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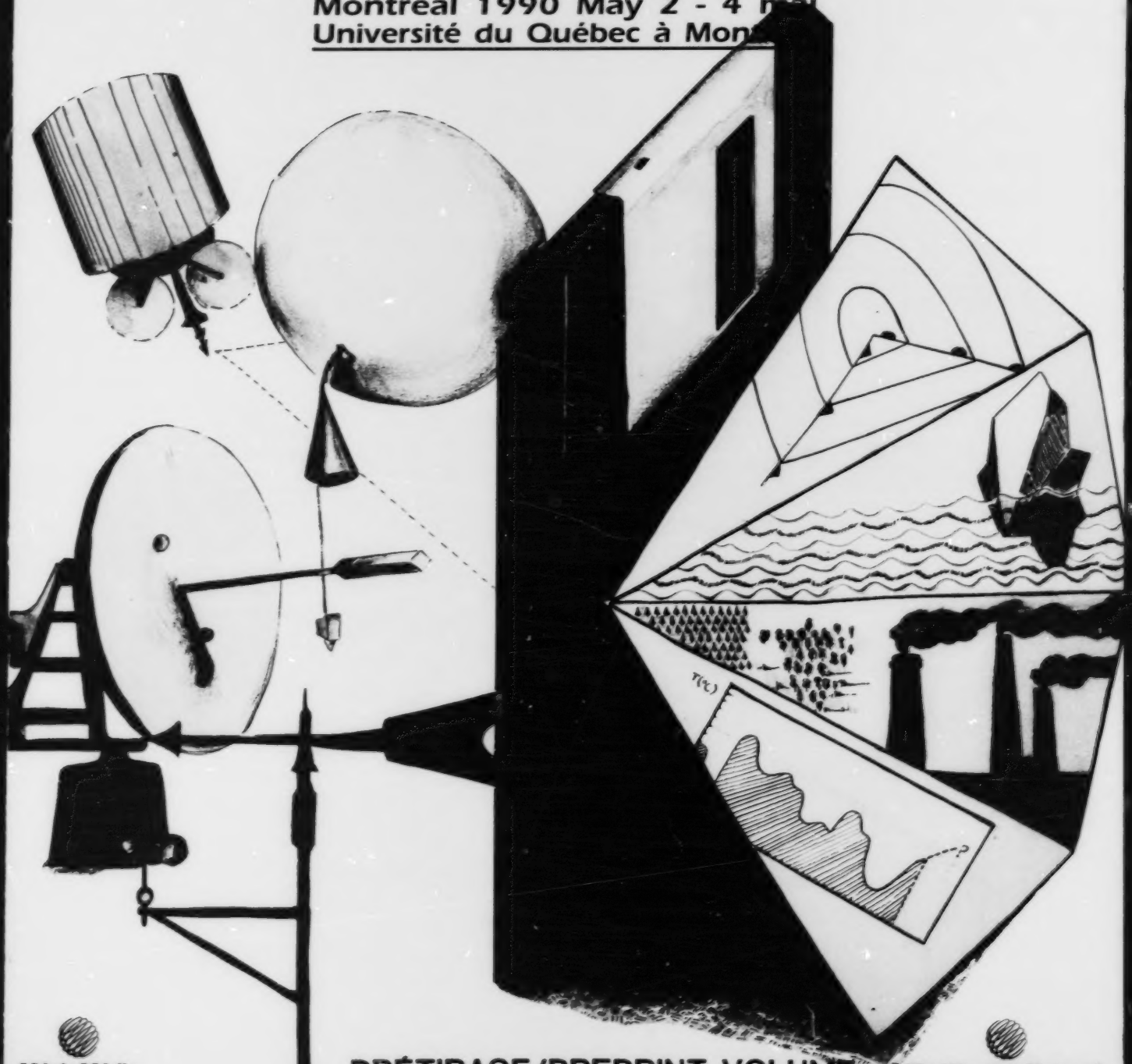
Canadian Meteorological and Oceanographic Society

3ième Atelier de travail
MÉTÉOROLOGIE OPÉRATIONNELLE

3rd workshop on
OPERATIONAL METEOROLOGY

Montréal 1990 May 2 - 4 mai
Université du Québec à Mon



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The Weather Network

L'Université du Québec à Montréal
accueille chaleureusement
le Troisième atelier de travail
sur la météorologie opérationnelle
organisé par
la Société canadienne de
météorologie et d'océanographie
et le Service
de l'environnement atmosphérique
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Université du Québec à Montréal
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Third Workshop on
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sponsored by the
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L'Université du Québec à Montréal, par l'intermédiaire de son département de physique, participe activement aux activités d'enseignement et de recherche en météorologie.

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Monique Leclerc, Ph.D. (Université de Guelph)-Micrométéorologie
Enrico Torlaschi, Ph.D. (Polytechnique de Milan)-Radarmétéorologie
André Robert, Ph.D. (Université de Laval)-Modélisation numérique
Isztar Zawadzki, Ph.D. (Université McGill)-Physique de la précipitation et radarmétéorologie
Peter Zwack, Ph.D. (Université McGill)-Météorologie synoptique et opérationnelle

Le **Groupe en sciences de l'atmosphère** à l'UQAM collabore activement avec d'autres groupes de la région montréalaise, tels que le département de météorologie et le Groupe de recherche sur les intempéries de l'Université McGill, le Groupe de recherche en prévision numérique (RPN) du Service de l'environnement atmosphérique, le Centre météorologique du Québec, le Centre météorologique canadien et le Centre de recherche informatique de Montréal (CRIM), ainsi qu'avec plusieurs autres institutions au Canada et à l'étranger.

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André Robert, PhD (Laval University) - Numerical Modelling
Isztar Zawadzki, PhD (McGill University) - Precipitation Physics and Radar Meteorology
Peter Zwack, PhD (McGill University) - Synoptic and Operational Meteorology

The Atmospheric Sciences Group at UQAM collaborates actively with other groups in the Montreal region, such as McGill University's Meteorology Department and the Stormy Weather Group, the Numerical Prediction Research Group (RPN) of the Atmospheric Environment Service, the Québec Weather Centre (CMQ), the Computer Research Institute of Montreal (CRIM), as well as a number of institutions elsewhere in Canada and abroad.

Université du Québec à Montréal

91-06699/

3ième ATELIER DE TRAVAIL EN MÉTÉOROLOGIE OPÉRATIONNELLE

DU 2 AU 4 MAI 1990
MONTRÉAL, QUÉBEC

Service de l'environnement atmosphérique

Société canadienne de météorologie

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3rd WORKSHOP
ON
OPERATIONAL METEOROLOGY

MAY 2-4, 1990
MONTRÉAL, QUÉBEC

Atmospheric Environment Service

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NOTE PRÉLIMINAIRE

Le Service de l'environnement atmosphérique (SEA) soutient depuis toujours la formation de son personnel opérationnel qui fournit les services météorologiques au Canada. Dans cette perspective, le SEA a demandé à la Société canadienne de météorologie et d'océanographie d'organiser le Troisième atelier de météorologie opérationnelle afin de satisfaire aux objectifs suivants:

- -contribuer à l'amélioration du service météorologique en fournissant un forum pour le transfert et le partage de l'expérience et des connaissances traitant de la météorologie opérationnelle;

- -identifier les besoins et priorités ainsi que promouvoir la recherche et le développement dans les domaines de la météorologie opérationnelle et de la prestation des services météorologiques;

- -fournir une occasion de rencontre entre les météorologistes opérationnels, les techniciens, les éducateurs ainsi que les gestionnaires impliqués dans tous les aspects des services météorologiques.

L'implantation du Plan stratégique prévue pour cette décennie aura comme résultat une modernisation et une restructuration importante du service météorologique canadien. Le personnel impliqué dans les services météorologiques aura à developper des habiletés de marketing afin de sonder les besoins des usagers et d'adapter leurs services en conséquence. Les prévisionnistes seront obligés de s'adapter à un nouvel environnement de travail et d'être à la fine pointe des connaissances nouvelles particulièrement à l'échelle méso. Les deux premiers ateliers ont eu lieu à Winnipeg (février 1986) et Halifax (octobre 1987). On espère que cette réunion s'inscrira dans la lignée d'une série d'ateliers fournissant un cadre permettant une interaction efficace entre les météorologistes opérationnels, le personnel des services météorologiques, les chercheurs et les gestionnaires.

Stan Siok Peter Zwack

Co-présidents, Comité de programme
Troisième atelier de travail sur la météorologie opérationnelle

FORWARD

The Atmospheric Environment Service (AES) has an extensive on-going requirement for training of operational personnel who provide weather services in Canada. In this perspective, the Canadian Meteorological and Oceanographic Society (CMOS) has therefore been contracted by AES to hold the Third Workshop on Operational Meteorology satisfying the following training objectives:

- to contribute to improvements in the Weather Service System by providing a forum for the transferring and sharing of knowledge and experiences dealing with operational meteorology;

- to identify needs/priorities and promote research and development in both the field of operational meteorology and the provision of weather services;

- to provide for an opportunity for interaction among operational meteorologists, technicians, researchers, educators and managers concerned with various aspects of the Weather Service System.

In the 1990's, implementation of the AES Strategic Plan will result in a significant modernization and restucturing of the Canadian Weather Service. Weather service personnel will be called upon to develop marketing skills in gauging user requirements and to adapt services according to user needs. Forecasters will be required to adapt to a work station environment and to keep abreast of new knowledge - particularly of the meso-scale. The first two workshops were held in Winnipeg (early February 1986) and in Halifax (October 1987). It is hoped that this gathering will be one of a continuing series of workshops providing an effective framework for interaction among operational meteorologists, weather service personnel, management and researchers.

Stan Siok

Peter Zwack

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AVIS/NOTICE

Plusieurs des résumés en français des articles américains et de certains articles canadiens sont une traduction libre faite par l'éditeur du volume de prétirage. Nous espérons qu'ils sont le plus fidèles possibles aux intentions des auteurs qui ne peuvent en vérifier l'exactitude.

Many of the french abstracts of american and canadian papers are translations provided by the editor. We hope that they convey the intentions of the authors.

Richard Moffet
Michel Jean

WEATHER SATELLITE OBSERVATIONS IN THE MESOSCALE FORECASTING ERA

By

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Abstract

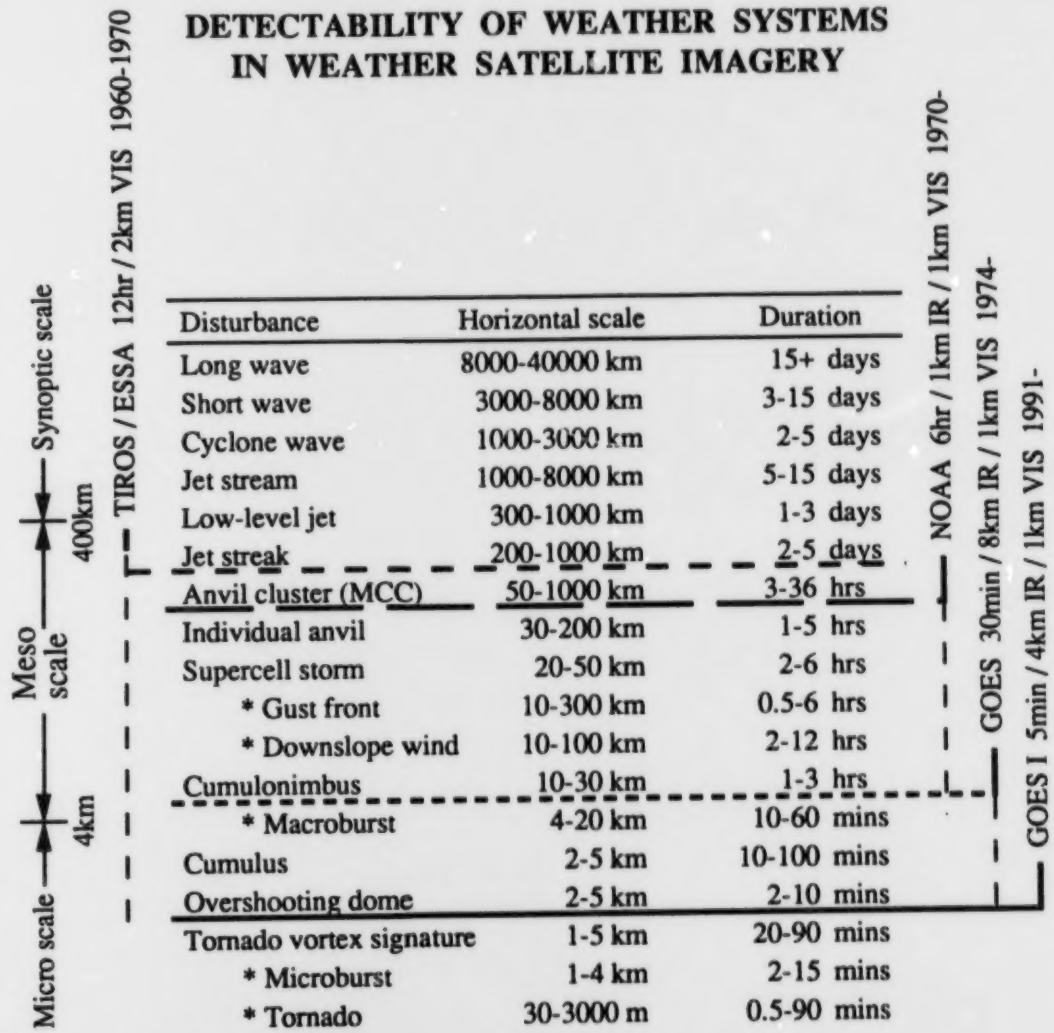
Over the past 20 years, studies of mesoscale cloud system evolution as viewed from space, have provided new insights concerning mesoscale processes which have had practical forecast application. To date, many of these applications have been limited to special forecast centers, but as communications and data processing technology improve the field use of satellite data should reach its full potential for mesoscale applications. Data from the new operational sensors on both polar and geostationary satellites will also bring new information for use in mesoscale forecasting.

Dans les vingt dernières années, la compréhension des processus de la mésoéchelle a beaucoup évolué grâce à l'étude des systèmes nuageux à mésoéchelle vus de satellites et a mené à des applications pratiques en prévision. A ce jour, ce sont les centres de prévisions spéciaux qui en ont surtout profité mais, à mesure que les communications et le traitement des données progressent, leurs applications à mésoéchelle devraient atteindre leur plein potentiel pour tous les météorologues. Les données provenant de nouveaux capteurs à bord des satellites géostationnaires ou polaires vont aussi amener de nouvelles informations pour la prévision à mésoéchelle.

I N T R O D U C T I O N

The first TIROS weather satellite images in 1960 provided meteorologists with their first look at mesoscale cloud formations. The early polar orbiter and geostationary satellite imagery revealed much new information about mesoscale circulations and particularly the evolution of convective mesoscale weather systems. Over the years, observations obtained in research field experiments have helped to explain the atmospheric processes responsible for the mesoscale cloud pattern evolution observed by satellites. This has led to success in using satellite data for operational nowcasting where communication and data processing capabilities are sufficient for timely data analysis and forecast dissemination.

DETECTABILITY OF WEATHER SYSTEMS IN WEATHER SATELLITE IMAGERY



Disturbance	Horizontal scale	Duration
Long wave	8000-40000 km	15+ days
Short wave	3000-8000 km	3-15 days
Cyclone wave	1000-3000 km	2-5 days
Jet stream	1000-8000 km	5-15 days
Low-level jet	300-1000 km	1-3 days
Jet streak	200-1000 km	2-5 days
Anvil cluster (MCC)	50-1000 km	3-36 hrs
Individual anvil	30-200 km	1-5 hrs
Supercell storm	20-50 km	2-6 hrs
* Gust front	10-300 km	0.5-6 hrs
* Downslope wind	10-100 km	2-12 hrs
Cumulonimbus	10-30 km	1-3 hrs
* Macroburst	4-20 km	10-60 mins
Cumulus	2-5 km	10-100 mins
Overshooting dome	2-5 km	2-10 mins
Tornado vortex signature	1-5 km	20-90 mins
* Microburst	1-4 km	2-15 mins
* Tornado	30-3000 m	0.5-90 mins

* Weather systems on or near the ground

Adapted from FUJITA (1986)

Table 1.

Synoptic and mesoscale meteorological phenomena which can be detected in satellite data and which are important for analysis and forecasting appear in table 1. They are ordered by horizontal scale and duration of life cycle using the classification of Fujita (1986). Mesoscale phenomena in this classification range from 4 to 400 km in size and can last from 10 minutes to three days. Table 1 also shows the capability of polar and geostationary satellites, both past, present and future, to detect and track the satellite signatures associated with these circulations. Satellite capabilities are indicated in terms of sensor resolution and operational imaging frequency; this information appears at the sides of the table. The horizontal lines across the table show the limits in the capability of each generation of satellites to detect cloud features. The vertical dashed lines relate the spatial resolution capabilities for each satellite system to weather system size. The sensor resolution of early polar satellites revealed many mesoscale cloud systems but these could not be properly interpreted for immediate use in mesoscale analysis and forecasting. This had to await studies of cloud system evolution based on frequent interval geostationary data.

MESOSCALE PROCESSES REVEALED IN SATELLITE CLOUD IMAGERY

The effects of many of the processes which are important for understanding and forecasting mesoscale weather systems can be observed in satellite cloud imagery. Those which have been identified over the years are listed in figure 1. Some of these were revealed for the first time in animated satellite imagery. These include: the role convective scale interaction in the formation of new thunderstorms (Purdom, 1973); the Mesoscale Convective Complex (MCC) and its life cycle (Maddox, 1980); the relationship of thunderstorm anvil growth to severe weather (Adler and Fenn, 1977) and to heavy rain (Scofield and Oliver, 1977); the relationship of overshooting cloud tops and warm spots to tornados and downbursts (Fujita, 1978); the importance of differential heating in the initiation of convection (Purdom and Gurka, 1974); and the role of horizontal mixing in the dissipation of mesoscale regions of fog and stratus (Gurka, 1978).

Mesoscale ciculations are responsible for localized heavy rain, snow and strong winds within synoptic scale storms. Their presence can often be detected in the structure of the storm's cold cloud tops. Changes in shape, growth and decreasing temperature of cloud top elements help identify these significant weather areas (Scofield and Spayd, 1984). In areas of post frontal cold air advection over the oceans, the organization of convective clouds provide important information for diagnosing and forecasting local weather changes not easily deduced from the current conventional observation system.

MESOSCALE PROCESSES REVEALED IN SATELLITE IMAGERY

1. Initiation of convection
   - o Sea and lake breeze fronts
   - o Peninsula and bay convergence effects
   - o Differential heating caused early morning clouds
   - o Interaction of convective cloud lines and arcs with mesoscale airmass boundaries
   - o Mountain slope effects
   - o Strong ocean surface temperature gradients
   - o Intersecting cloud lines

2. Convective system evolution
   - o Squall line development
   - o Mesoscale Convective Complexes (MCC)

3. Strong Convection
   - o Overshooting tops
   - o Enhanced V formation
   - o Rapid anvil expansion
   - o Rapid top warming

4. Low level advection
   - o Cold air advection over warmer surface: cloud line and cellular patterns
   - o Warm air advection over colder surface: fog and stratus

5. Barrier effects
   - o Mountain wave clouds
   - o Mountain cirrus plumes
   - o Downstream cloud lines and vortex streets

6. Horizontal mixing
   - o Fog and stratus dissipation

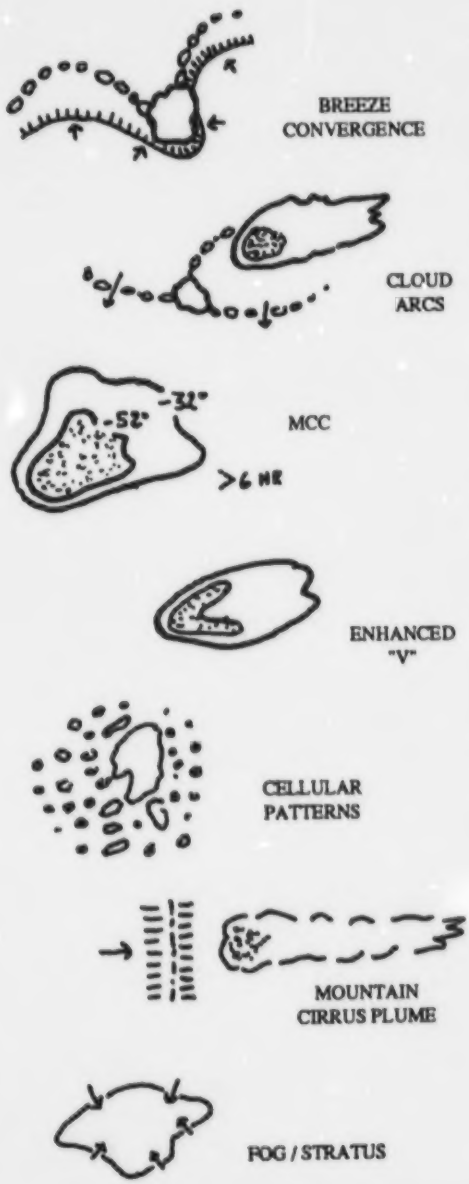


Figure 1.

Several field experiments have been held in the past decade to improve our understanding mesoscale weather. Examples of these are the Cooperative Huntsville Meteorological Experiment (COMEX) held in 1986 to study small convective and mesoscale systems and the Experiment on Rapidly Intensifying Cyclogenesis in the Atlantic (ERICA) conducted in 1988-9. The goal of ERICA was to study mesoscale interactions with the synoptic scale during rapid cyclogenesis. These experiments have provided mesoscale ground truth observations which help us to better understand satellite cloud imagery and use it for nowcasting.[1]

CURRENT SATELLITE MESOSCALE APPLICATIONS

Imagery is the primary type of satellite measurement currently used in operations for mesoscale analysis, nowcasting and short range forecasting. To be used effectively, data must be received in near real time and at a frequency which matches the scale of the mesoscale weather systems being diagnosed and forecast. All channels should be available and at the highest resolution. Image analysis should take place on an interactive workstation which is powerful enough to apply enhancement and animation techniques. The workstation should also be capable of superimposing other observations and graphical analyses over the satellite imagery in real time. But even where these capabilities exist, a nowcast or short range forecast program is not successful unless comunications are rapid enough to provide the forecast to users within a time frame which allows them to take appropriate action. In the United States, the combination of these capabilities has been limited to national centers, experimental demonstration projects and support to research field experiments.

Severe Convective Storms

The most successful operational application of satellite data to short range forecasting in the U.S. during the 1980's has been at the National Severe Storms Forecast Center (NSSFC) at Kansas City. Here, direct satellite readout provides realtime data receipt at 15 minute frequency and an operational version of the Man-computer Interactive Data Access System (McIDAS) furnishes high quality animated imagery as well as interactive analysis capability. Severe storm forecasters are able locate and track small scale disturbances in the upper flow which trigger convective storm outbreaks; they can assess the relative stability of different areas from rates of convective cloud development; they can examine

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[1]Nowcast is defined here as a detailed description of current weather and a forecast that includes the weather from convective and other mesoscale phenomena with durations which average 30 minutesto 4 hours. A short range forecast is defined as extending to 12 hours and dealing with mesoscale phenomena at the upper end of the time and space scale.

low level cloud fields to locate mesoscale boundaries which are important in the initiation of severe convection; and they can monitor moisture and stability changes hourly using experimental multispectral image products. These capabilities have contributed to increased skill for the severe convective storm watches and made it possible to alert offices with warning responsibilities when satellite severe storm signatures are detected in warning areas.

The current GOES satellite series has an eleven channel sounding capability from the VISSR Atmospheric Sounder (VAS) instrument which was first flown in 1980. There has been much effort to use this frequent interval (three hourly) sounding data for severe convective storm forecasts at NSSFC. Experimental data from this instrument has been most successful in identifying mesoscale gradients of precipitable water and stability. The soundings and quantitative grid data produced from the VAS have not proved opperationally useful because of sensor limitations: limited number of channels, low spin budget and no ability obtain soundings in cloudy areas. The most successful VAS products have been lifted index and total precipatable water which are supplied to forecasters as animated images.

Hazards to Aviation

Severe thunderstorms, heavy rain, downbursts and fog all affect aircraft operations. Since most aircraft flights are two hours or less, the information concerning these hazards that can be derived from satellite imagery must be analyzed and quickly delivered to the users: pilots, air traffic controllers and tower operators. To some extent, this has been possible since the NSSFC is also responsible for issuing significant weather advisories (SIGMETS) for inflight hazards over the U.S. Again, the McIDAS is used for data analysis.

National Weather Service (NWS) meteorologists are also located at Federal Aviation Administration (FAA) regional Aircraft Traffic Control Centers as well as the FAA Central Flow Control Facility in Washington. The FAA centers only receive the standard GOESFAX satellite imagery at 30-minute intervals and no interactive analysis capability exists. In spite of these deficiencies, there has been limited successful mesoscale use of the data at these locations. This is because the forecaster is able to speak directly to the controllers who, in turn, can talk directly to pilots when necessary, thus ensuring timely delivery of the mesoscale nowcast.

Flash Floods

Operational mesoscale precipitation estimates (Scofield, 1987) are currently produced by the National Environmental Satellite, Data, and Information Service (NESDIS) at the National Meteorological Center (NMC) in Washington. Areal rain estimates are produced hourly based on an analysis of visible and IR

imagery. The analysis is done interactively on an operational version of the McIDAS. The computer totals rainfall amounts at the resolution of each IR pixel and automatically generates and transmits messages to NWS field offices which include the estimated hourly rainfall rate and the total accumulation by county. The messages reach the user 20 to 30 minutes after receipt of the last satellite image used.

Mesoscale Convective Systems (MCS) are one of the major sources of heavy convective rainfall responsible for flash floods. Recently, Juying and Scofield (1989) have developed a procedure for nowcasting the propagation of MCS's. The procedure uses satellite imagery, the 850 mb Oe analysis, thickness fields and stability parameters. This procedure is useful to identify the direction of storm propagation which can be different than that indicated by steering currents.

Marine Applications

There is currently not much use of satellite data for mesoscale marine forecasts since there is no requirement for such forecasts over the high seas. Forecasters responsible for coastal zone forecasts generally do not yet have the analysis capability nor the means of communicating nowcasts of hazardous weather for these regions.

In the mid-seventies there was a nowcasting experiment for Chesapeake Bay (Scofield and Weiss, 1977) to demonstrate the use of the NOAA weather radio for providing the boating public with wind and weather conditions over the northern half of the bay. The experiment ran for three summers and included special hourly reports from cooperative observers which were plotted and analyzed in conjunction with satellite and radar imagery. Data obtained during the experiment was used to develop conceptual models of sea breeze regimes based on cumulus cloud patterns. An attempt was also made to relate the onset and strength of the bay breeze to hourly changes in the land and sea surface temperatures as measured by the GOES IR sensor. This experiment had the proper communications for receiving data and timely dissemination of the mesoscale forecast, but the technology was not yet developed for processing the data so the concept could not be transferred to operations.

C O M I N G S A T E L L I T E S Y S T E M S

GOES I-M

The next generation geostationary satellite, GOES I (Bradley, 1988), will have many improved capabilities over the current GOES series. The spacecraft will be three-axis stablized and there will be independent instruments for imaging and sounding. The imager will have 5 channels with IR resolution improved to 4 km for the thermal channels and 8 km for the water vapor channel. The sounder will have 19 channels instead of the current 11 for

the VAS. Operational images will be available at 30, 15, and 5 minute intervals depending on the weather situation. The initial GOES I products produced by NESDIS for the NWS will include those currently provided, new ones from the sounder based on the VAS experience and new mapped imagery to support the NWS modernization program. GOES I is expected to be launched in the latter part of 1991 and about six months will be necessary to checkout the new system before products can be distributed. Satellite imager products will be available first; satellite sounder products will require more extensive validation and evaluation.

NOAA KLM

NOAA K which is planned for launch in December, 1993 will have a new sounding instrument, the Advanced Microwave Sounding Unit (AMSU-A), with 15 channels. AMSU-B will follow at a later date and have five additional channels for moisture profiles. The resolution of the microwave sensor will increase from 110 km to 40 km at nadir. This will greatly improve the quality of soundings in cloudy areas. The High Resolution IR Sounder (HIRS) will continue on NOAA K but with 3 less channels.

C O N C L U S I O N

Observations of the clouds associated with mesoscale circulations have been available from operational geostationary satellites since the mid seventies. Research conducted during the first 5 to 8 years of GOES identified applications of GOES data to nowcasting and short range forecasts on the mesosccale. Widespread use of the data for this purpose has been limited by the communications available at forecast offices both to receive appropriate satellite imagery and to transmit mesoscale forecasts to the user. An additional limitation has been the lack of imagery analysis capability at operational sites. These conditions are changing as new less expensive technology is adopted for meteorological operations and mesoscale analysis and forecasting receive increased attention.

But at the same time, the 1990's will bring increased quantities of observations from new satellite sensors and other remote sensing sources such as doppler radar and atmospheric profilers. New ways must be developed to assimilate this additional data for use in mesoscale analysis and forecasting. Ways must be found to incorporate the quantitative mesoscale temperature and moisture information obtainable from weather satellites into mesoscale numerical forecast models. This especially applies to data available from the microwave sensor on the new NOAA KLM satellites. New automated methods need to be developed which combine satellite data and other current observations to produce quantitative parameters which can be applied directly to nowcasting. New methods are also needed to directly compare mesoscale numerical forecasts with satellite and other observations in order to quickly identify when and where forecasts

are deviating from real atmospheric change. These are the challenges for integrating satellite data into weather service mesoscale operations in the future.

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TRENDS IN NUMERICAL WEATHER PREDICTION

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ABSTRACT

The evolution of numerical models over the past 30 years is reviewed briefly. An effort is made to identify changes that indicate a trend for the future. Long term efforts aimed at improving the stability, the accuracy and the efficiency of numerical models are discussed and related techniques are described. Some emphasis is placed on techniques that are presently being tested and will most likely be implemented in the next five to ten years.

RESUME

Une brève revue de l'évolution des modèles numériques au cours des trente dernières années est effectuée. Un effort est fait afin d'identifier les changements qui représentent une tendance pour le futur. Les efforts à long terme visant à améliorer la stabilité, la précision et l'efficacité des modèles numériques sont décrits. L'emphase est placée sur les techniques qui sont présentement à l'essai et qui vont probablement être implantées au cours des prochaines cinq à dix années.

1. INTRODUCTION

When the first numerical models were integrated on electronic computers, the meteorologists and other scientists associated with this work spoke of a breakthrough that would have an immediate impact on the art of weather forecasting. The expected sudden improvement in forecast accuracy never occurred. What was noticed in reality was a slow gradual improvement that started in 1958 and maintained a nearly constant rate until present times. Everything seems to point to the fact that this evolution will continue for at least another 50 years. The only foreseen barrier from the scientific point of view is the so-called "ultimate limit of predictability". Since this barrier is associated with the initial value approach, it seems most likely that the modellers will eventually find other ways of launching their integrations in order to go beyond this limit.

For the time being, it still seems that everything can be improved in numerical models. This is enough to cause an enormous amount of optimism but on the other hand, if we take our lesson from the past 30 years, we must recognize that the progress will appear as quite slow to those who have to live with the present imperfections in weather forecasts.

2. THE MODEL EQUATIONS

Early models used the non-divergent or quasi-geostrophic barotropic vorticity equation applied at the 500 mb level. This equation was integrated on a grid of the order of 30 by 30 points with a spacing of the order of 400 km. The main reason for this was that the computers available were not powerful enough to do any better than this. As time evolved, quasi-geostrophic baroclinic models with five to ten levels in the vertical became quite common. Some small Centers still use quasi-geostrophic models. These models can produce fairly good forecasts but they contain approximations that cannot be removed and they do not perform too well in important meteorological situations.

In 1967, the National Meteorological Center in Washington implemented its first model of the primitive meteorological equations. Immediately, the monthly averaged verification scores started beating all previous records and they continued to improve afterward. Nearly all the models used at the large Centers today are based on the primitive equations. They require about six times more computing power than the corresponding quasi-geostrophic models, but on the other hand, they contain only one approximation. This is

the hydrostatic approximation which is considered to be quite accurate at the synoptic scale.

In the last ten years, the extra cost in computing associated with the primitive equations has been recovered through the implementation of semi-implicit or split-explicit integration schemes. These developments will be discussed in the next section.

Hydrostatic models are now being used with very fine grids to study meso-scale phenomena. At these scales, the validity of this approximation becomes questionnable. Models used for the study of convective phenomena use another approximation called the anelastic approximation, but again, it is not sure that this approximation can be extended to the synoptic scale.

Over the last 15 years, a few models that do not resort to the approximations mentioned above were built by Tapp and White, Klemp and Wilhelmson and Cotton and Tripoli. These models include sound waves and are based on the Euler equations and are called compressible equations models. The first model mentioned above applies a semi-implicit scheme to the sound waves while the other two use a split-explicit scheme for the same purpose which consists in avoiding the use of unreasonably short time steps.

Last year, Tanguay, Robert and Laprise integrated a synoptic scale model based on the Euler equations with a time step of 30 minutes. This is a time step 700 times longer than what would normally be used in a model that contains sound waves. This result was achieved by applying a semi-implicit scheme to both the sound waves and the gravity waves. An additional enhancement consisted in applying a semi-Lagrangian scheme for the treatment of advection.

It was concluded from this study, that the hydrostatic approximation used in all synoptic scale models can be eliminated at no extra cost in computing power. The resulting model also becomes a universal model in the sense that it can be used and will remain accurate at all meteorological scales from 100 meters to 40,000 km. It is believed that most models used for numerical weather prediction will eventually stop using the hydrostatic approximation.

3. NUMERICAL METHODS

For a period of 20 years, all operational models were grid point models. Unfortunately, these models contained a lot of problems and in most cases, it was instabilities that developed during the integration that caused most of the concern. Some of the early baroclinic models would blow up about three times a week and in such situations they did not produce any forecast. Those who built models were primarily concerned with the stability of their formulations. They did not have enough time to pay much attention to the accuracy of the forecasts that they produced.

These instabilities were poorly understood so that the tendency was to use filters that masked these problems. Some models used the Euler-backward

integration scheme because of its ability to damp high frequency waves. When a five day hemispheric forecast was produced with this algorithm, the resulting height and temperature fields were almost perfectly circular around the north pole. Arakawa devised energy preserving finite difference formulations that contributed significantly to stabilize integrations.

At an early stage, most models started using the leapfrog scheme because this algorithm was simple, it was of second order accuracy and it did not damp waves. Many new problems appeared when this scheme was implemented. Restart procedures had to be applied every 12 hours in order to eliminate the computational mode. Global grids had problems near the poles and limited area grids had problems with the lateral boundaries. A wide variety of finite difference formulations could be formulated. There were as many formulations as there were models and most of them contained problems.

The use of grid point formulations was so discouraging that some scientists started examining spectral formulations. Baer ran a spectral model of the non-divergent vorticity equation in 1961. The main characteristic of the spectral formulation is that it is unique. All spectral models used today are identical in the sense that they all use the same technique (least squares) to truncate their results. Also, all derivatives are computed exactly. Grid point models generally underestimated the displacement of waves because of the truncation errors associated with the calculation of derivatives.

Early spectral models were very time consuming compared to grid point models (nearly two orders of magnitude). Also, they required a huge number of interaction coefficients even at low resolution for the treatment of nonlinear terms. In spite of this, spectral models of the primitive equations were built and tested.

The interest for spectral models started growing when a semi-implicit integration scheme was incorporated in such a model. At first, it seemed that it might not be possible to use such a scheme in a grid point model. A complete change in attitude towards spectral models occured in 1970 when Machenhauer implemented the transform method in a spectral model of the primitive equations. All interaction coefficients were eliminated and the computations were reduced by a factor of 15. Shortly afterwards, Machenhauer tested with success a normal mode initialization scheme This technique was designed to eliminate spurious gravity waves without affecting the Rossby modes. It was more effective than the dynamic initialization schemes that were used at that time. This method was so heavily linked to the spectral formulation that it was believed that it might never be incorporated in a grid point model. In fact it took about 15 years before an equivalent formulation was developed for a grid point model.

The first spectral models were implemented in Canada and Australia in 1976, at NMC in 1980 and at ECMWF (European Center for Medium-Range

Weather Forecasts) in 1983. Nearly all global models used today are spectral models.

The main advantage of the spectral method is that it is relatively free of numerical instabilities. This is one of the reasons for its popularity. On the other hand, it must be recognized that grid point models also progressed considerably during that period. Staggered grids and the finite element method contributed significantly towards the progressive elimination of numerical instabilities. The so-called "Arakawa-C staggered grid" is quite popular and is used in a large number of models. The time filter used with the leapfrog scheme and slow start procedures also contributed to stabilize integrations. Most of the problems associated with the lateral boundaries in nested models have been eliminated. Grid point models are still the most popular and their popularity stems from the fact that with the help of nesting techniques, they can be used for regional weather prediction and also for mesoscale prediction studies. Countries such as the United Kingdom and France use mesoscale models to produce their operational short range weather forecasts.

Once that a satisfactory control of numerical instabilities was obtained principally in spectral models, some efforts went into the development of efficient numerical techniques. The transform method and the fast Fourier transform belong to this category. These were introduced in spectral models, but eventually the fast transform became very popular for the solution of elliptic partial differential equations.

The semi-implicit time integration scheme is another technique that is now widely used in numerical models. This scheme makes it possible to enlarge the time step by a factor of six in large scale models with no noticeable loss of accuracy. Split-explicit schemes also achieve the same result. When a semi-Lagrangian integration scheme is coupled with the semi-implicit scheme, it becomes possible to enlarge the time step by another factor of four to six. Such a technique was implemented in an operational model in Ireland in 1982 and later in 1987 in the Canadian operational finite element model. Semi-Lagrangian schemes are presently being tested in spectral models in Canada and at the ECMWF. This technique might make its way into a large number of operational models over the next ten years.

The multi-grid method is another highly efficient numerical scheme worth mentioning. It is still in its early stages of development. It is used primarily for the solution of elliptic partial differential equations but it may eventually find other applications.

The numerical problem at the poles that plagued global grid point models for 30 years was solved recently by Macdonald and Bates. At high resolution, grid point models are more efficient than spectral models. It seems most likely

that the high resolution global spectral models will eventually be replaced by global grid point models.

4. PROBABLE TRENDS FOR THE NEXT 10 YEARS

Discoveries or major developments will continue to occur occasionnally as they did in the past. These occurences are unpredictable by nature. On the other hand, past experience tells us that major developments generally take more than ten years before they make their way into operational models so they do not have to be taken into account.

A list of expected trends that will make their way into operational models is given as follows:

1. The number of models that use semi-Lagrangian schemes will increase significantly.
2. The number of models that use the Euler equations (non-hydrostatic) will also increase significantly.
3. The parameterization of physical processes will become the number one priority of most Centers at the expense of numerical and dynamical aspects of modelling.
4. Spatial resolution will continue to increase steadily.
5. Implicit normal mode initialization schemes will be used extensively in regional models.
6. There will be a substantial increase in the number of regional models that use a global model as a driver.
7. The spectral method will be used in several regional models.
8. The multigrid method will start being used extensively.
9. The number of global spectral models will remain stable or will decline sligthly while the number of grid point models will increase substantially.

In conclusion, it seems that in the field of numerical weather prediction, the future will simply be a continuation of the past and present developments. The main reason for this is that the life span of numerical models is increasing in such a way that about 30% of existing models will still be used in ten years. On the other hand, the overall performance of models will continue to increase steadily.

CONCEPTUAL MODELS OF ATMOSPHERIC FRONTS

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ABSTRACT

A brief review is presented of conceptual models of atmospheric fronts, with the intent of providing a framework for describing and understanding frontal structure and dynamics, as well as associated vertical circulations and cloud and precipitation distributions. A dominant theme of the review is the role of advances in observing and computing technology in the emergence and refinement of conceptual models. The review begins with the classic Norwegian polar-front cyclone model, the influence of which continues through today in the analysis of surface fronts within midlatitude cyclones. The establishment of upper-air observing networks led to the discovery of upper-level fronts and modification of the polar-front model of midlatitude cyclones to describe the three-dimensional structure and evolution of baroclinic waves. The synthesis of satellite and radar observations with the principles of isentropic analysis is shown to culminate in the airstream models of Browning and collaborators and Carlson. Very recently, the synthesis by M. A. Shapiro and colleagues of high-resolution numerical simulations and aircraft observations of intense oceanic cyclones suggests a novel alternative for frontal analysis in midlatitude cyclones.

INTRODUCTION

A remarkable property of midlatitude flows is for spatial variations of wind and temperature to become concentrated into long and narrow sloping zones referred to as fronts. These phenomena typically are an order of magnitude longer than they are wide (~1000–2000 km compared with ~100–200 km), and are ~1–2 km deep. Thus, the along-front dimension is synoptic scale (corresponding to the Rossby radius of deformation), whereas the cross-front dimension is mesoscale. Under certain circumstances, cross-frontal scales of microscale (~1–2 km) dimensions have been observed near the surface, with the leading edge of fronts possessing a gravity-current–like configuration (Shapiro et al., 1985; Smith and Reeder, 1988). By virtue of being transition zones in the wind and temperature fields, fronts are characterized by large values (relative to the background flow) of horizontal temperature gradient, static stability, the vertical component of vorticity and vertical wind shear. Finally, fronts owe their kinematic origin to the deformation fields characteristic of midlatitude baroclinic flow regimes. Synoptic-scale deformation not only concentrates temperature and wind contrasts, but gives rise to secondary, divergent circulations that augment deformation-induced scale contractions.

It should be emphasized that not all phenomena assuming the form of relatively long, narrow lines meet the definition of a front, even if these phenomena are associated with significant weather. For example, shear lines (e.g., Holopainen and Rontu, 1981) consist of a very narrow trough flanked by oppositely directed flows with embedded jets on each side. Although they may contain frontal zones associated with the flanking jets, shear lines are not usually considered to be fronts. Similarly, inverted troughs (e.g., Keshishian, 1989) are properly viewed as thermal ridges and regions of pronounced warm advection, rather than fronts, since the vorticity and baroclinicity are not concentrated into a narrow zone. Furthermore, a distinction should be made regarding front-like features that appear to be dominated by orographic and boundary-layer processes, such as backdoor cold fronts and coastal fronts found along the east coast of the United States (e.g., Bosart et al., 1973; Bosart, 1975) and their counterparts in other parts of the world. Although this class of fronts may be accompanied by significant weather, they do not appear to be generated by synoptic-scale deformation.

With the foregoing qualifications in mind, we focus attention in the remainder of this review on frontal systems associated directly with midlatitude cyclones and the upper-level waves that often precede and accompany their development. This approach calls for discussion starting with the classic Norwegian polar-front cyclone model (Bjerknes, 1919; Bjerknes and Solberg, 1921, 1922), since it is widely appreciated that this is the first conceptual model to incorporate systematically the evolution of fronts through the life cycle of midlatitude cyclones.

Before proceeding, it is noted that this review is not comprehensive, but is intended to provide the reader with a sketch of several conceptual models used to describe the structure and dynamics of frontal zones. Observational examples are excluded for brevity, but will be presented at the conference. For more complete reviews, readers are referred to appropriate sections of the textbook by Palmén and Newton (1969), the review article by Keyser and Shapiro (1986), and the book chapters by Bluestein (1986), Keyser (1986) and Shapiro and Keyser (1990).

THE POLAR-FRONT CYCLONE MODEL AND EXTENSIONS

In this model, fronts are considered to be sloping, material surfaces characterized by zero-order discontinuities in temperature and along-front wind. Cloud and precipitation distributions are related to upward motions resulting from airflow relative to inclined frontal surfaces. The illustration in Fig. 1 (Bjerknes and Solberg, 1922) displays four stages in the evolution of a midlatitude cyclone, which takes place on a pre-existing frontal zone separating polar from tropical air. The incipient frontal wave (stage I) amplifies through stages II and III, yielding cold and warm fronts, which occlude in stage IV. At this stage, the model portrays the "seclusion" of initially warm-sector air near the center of the cyclone. This feature deserves emphasis because of its reappearance in a contemporary conceptual model to be considered subsequently.

A popular perception is that the existence of fronts was not widely recognized until their identification by the Norwegian School in Bergen. Part of this perception is attributed to the limited number of references in the papers presenting the model to earlier work (Kutzbach, 1979, ch. 7) and to the slow pace of assimilation of polar-front concepts into operational practice in the United States (Namias, 1983; Bates, 1989). Nevertheless, in her historical monograph, *The Thermal Theory of Cyclones*, Kutzbach (1979) documents a diversity of frontal studies conducted during the nineteenth century. The originality of the polar-front cyclone model lies not in the discovery of fronts, but in their incorporation into a conceptual model appropriate to routine synoptic analysis. In addition to its operational value, the conceptual model was diagnostically useful in that it contributed the basis for inferring regions of ascent and precipitation. Finally, the model motivated theoretical studies of frontal instability, which continue to this day (e.g., Orlanski, 1968; Moore and Peltier, 1987).

The polar-front cyclone model pre-dated modern upper-air observing technology, so that vertical structure had to be inferred indirectly, e.g., from visually derived cloud motion winds. Thus, it is not surprising that the aspects of the model that were revised rather early on involved the vertical structure of frontal zones. The experimental use of balloon-borne meteorographs, supplanted by routine radiosonde observations by the 1930's (Palmén and Newton, 1969, pp. 131–132), resulted in the revision of the concept of a front from a discontinuity separating polar from tropical air (Fig. 2a) to that of a sloping transition zone extending through the depth of the troposphere (Figs. 2b and 2c) and even into the lower stratosphere (Fig. 2d). The shift in emphasis from frontal discontinuities to frontal zones among observationalists was undoubtedly encouraged by the introduction of quasi-geostrophic theory following World War II. Quasi-geostrophic theory was applied diagnostically to infer vertical motion patterns and rates of vorticity growth in midlatitude cyclones (e.g., Sutcliffe, 1947), and theoretically to investigate the stability of vertically sheared zonal flows to cyclone-scale disturbances [e.g., the pioneering studies of baroclinic instability by Charney (1947) and Eady (1949)].

Another shift in emphasis that occurred with the advent of baroclinic instability theory was that fronts form in response to the finite-amplitude development of infinitesimal perturbations on a zonal current, rather than in advance of cyclogenesis. A contemporary view (Eliassen, 1966) is that frontal instability may be responsible for the growth of short, shallow cyclone waves to finite amplitude (e.g., the weak, lens-shaped lows often observed on quasi-stationary fronts in noncyclogenetic situations), but that baroclinic instability is the dominant energy source for deep, intense midlatitude cyclones. It is possible that frontal instability accounts for the precursor perturbations found on low-level frontal zones that amplify with the approach of an upper-level disturbance (Petterssen, 1955; Farrell, 1984).

The concept of deep fronts separating polar and tropical air masses was challenged as researchers began to make systematic use of data from operational upper-air networks following World War II. Studies such as those of Reed and Sanders (1953), Newton (1954),

Reed (1955) and Sanders (1955) showed that fronts did not necessarily extend continuously from the surface to the tropopause; i.e., these studies showed that fronts found at various levels in the troposphere could be structurally and dynamically distinct. Particularly novel (and radical at the time) was the idea that upper-level fronts could develop entirely within a polar air mass, with horizontal temperature and wind contrasts generated by differential subsidence rather than through horizontal deformation and convergence (Reed, 1955). This discovery further downplayed the importance of the polar front, which was increasingly viewed as a statistical rather than as a synoptic entity. Figure 2e represents schematically an upper-level frontal zone and "tropopause fold," which have evolved in response to vertical deformation of the tropopause by a frontogenetical subsidence pattern.

The Newton-Reed-Danielsen model (Fig. 2e) has been refined since its introduction over thirty years ago, following the introduction of meteorologically instrumented aircraft as an observing platform during the 1960's and 1970's. An example of such a refinement, that emerging from the case studies of Shapiro (1974, 1976, 1978), is shown in Fig. 3. This model may be considered a hybrid of those in Fig. 2d (Nyberg-Palmén-Berggren) and Fig. 2e (Newton-Reed-Danielsen), in the sense that the tropospheric cyclonic shear zone extends into the lower stratosphere and the cold and warm boundaries of the frontal zone in the troposphere merge continuously with the tropopause.

In retrospect, it is apparent that many of the pioneering case studies of upper-level fronts focused on vertical structure and were restricted to portions of the life cycles of midlatitude cyclones and baroclinic wave systems. As described further in Shapiro and Keyser (1990), this resulted in differences in interpretation with regard to the sense of vertical circulations (direct vs. indirect), as well as the representativeness of various models of the vertical structure of frontal zones. In order to begin addressing these issues, Shapiro (1983) synthesized a schematic (Fig. 4) describing the interaction of an upper-level jet-front system with a synoptic-scale wave over North America. The schematic starts with the appearance of the jet-front system in a confluence zone resulting from the juxtaposition of polar and arctic flow regimes (Fig. 4a), continues with the jet in the northwesterly flow inflection upstream of a negatively tilted, "digging," diffluent trough (Fig. 4b), then depicts a cutoff low with the jet situated in the base of the trough (Fig. 4c), and finally concludes with the jet in the southwesterly flow inflection following the "opening up" of the cutoff and "lifting" of the trough as it becomes positively tilted and confluent. For further discussion, the reader is referred to the review by Keyser and Shapiro (1986, pp. 466-470).

The foregoing schematic of the evolution of an upper-level jet-front system relative to a synoptic-scale wave does not address low-level cyclone evolution. This neglect is consistent with the observation that many of the early frontal case studies, including those on which the schematic is based, treated upper- and lower-level fronts in isolation (Shapiro and Keyser, 1990). Thus, despite the advances in describing frontal structure and dynamics initiated during the 1950's, the polar-front cyclone model remained virtually unaltered and continued to serve as the mainstay of routine synoptic analysis, in both operations and research.

CONCEPTUAL MODELS BASED ON RELATIVE-FLOW ISENTROPIC ANALYSIS

The introduction of satellite and radar technologies set the stage for yet another class of conceptual models of midlatitude cyclones and fronts: those based on relative-flow isentropic analysis. This technique, introduced by Green et al. (1966), involves constructing relative-flow streamlines on isentropic surfaces (θ or θ_w, depending on whether a region is unsaturated or saturated). The "relative flow" refers to air motion with respect to an identifiable feature, such as a cyclone center or an upper-level vorticity maximum, which is assumed to be steady state. This assumption renders the relative streamlines equivalent to trajectories in the translating system. Further, the vertical motion is proportional to the component of the relative flow in the direction of the gradient of the height of isentropic surfaces; i.e., upward and downward motion occur respectively for upslope and downslope relative flow with respect to the isentropic topography. Despite these diagnostic advantages, the steady-state assumption appears to limit the technique to mature cyclones or to evolving cyclones during restricted portions of their life cycles.

In the case of mature midlatitude cyclones, the relative streamline pattern usually reveals several distinct airstreams characterized by differing initial altitude and geographical position. Referred to by K. A. Browning and collaborators as "conveyor belts," these airstreams tend to account for the shape and orientation of cloud features, such as the striking comma structure of mature midlatitude cyclones seen in satellite imagery. Cloud edges often coincide with boundaries between airstreams, which, in turn, may correspond to upper- and lower-level fronts. An example of a conceptual model of a midlatitude cyclone formulated in terms of the principles of relative-flow isentropic analysis by Carlson (1980) is reproduced in Fig. 5. This example displays three prominent airstreams: the warm and cold conveyor belts and the so-called dry airstream. The low-level boundary between the warm and cold conveyor belts corresponds to the warm front, whereas the boundary between the dry airstream and warm conveyor belt corresponds to the cold front. An upper-level frontal zone is found in the confluence zone constituting the sharp northern edge of the warm conveyor belt.

The conceptual models of airflow in midlatitude cyclones revealed by relative-flow isentropic analysis may be viewed as an elaboration of the three-dimensional character of the polar-front cyclone model applicable to frontal zones rather than to discontinuities (Keyser, 1986, pp. 248-252). Airstreams are analogous to air masses in the sense that they possess characteristic source regions, their properties are relatively homogeneous, and their boundaries consist of frontal zones. Vertical motions are determined from the flow relative to isentropic topography rather than frontal topography, as is the case with frontal discontinuities. This class of conceptual models remains useful because they facilitate the interpretation and diagnosis of satellite imagery in conjunction with conventional synoptic analyses and because they provide a basis for subjectively refining cloud and precipitation patterns predicted by numerical weather prediction models.

Satellite imagery of cold fronts associated with midlatitude cyclones sometimes shows cloud bands either predominantly confined to the cold-air side (post-frontal) or to the warm-air side (pre-frontal), consistent with the terminology of anafronts and katafronts introduced by Bergeron (1937) and explored observationally by Sansom (1951) in the context of the polar-front cyclone model. This classification distinguishes between fronts in which the warm air above the underlying cold wedge is rising or sinking, respectively. Browning (1985) reformulated these concepts using relative-flow isentropic analysis, stating the distinction in terms of the orientation of the poleward flow in the warm conveyor belt toward the cold-air side (Fig. 6) or the warm-air side (Fig. 7) of the cold front. These cases are referred to respectively as rearward and forward sloping ascent, and may be viewed as the contemporary counterparts of the anafront/katafront designations appropriate to the polar-front cyclone model. Further discussion of this terminology and a case-study example are found in the articles by Bennetts et al. (1988, 1989).

A REVISION TO THE POLAR-FRONT CYCLONE MODEL

The invention and proliferation of high-speed electronic computers following World War II provided meteorological researchers with an increasingly powerful tool for predicting and simulating the evolution of fronts and cyclones. As observed by Hoskins (1983), simulation experiments of cyclogenesis initialized with small-amplitude perturbations on zonal jets possessing lateral and vertical shear produced low-level frontal configurations that differ significantly from those in the Norwegian polar-front cyclone model. These differences either reflect shortcomings in the idealized formulation of the numerical models or deficiencies in the polar-front cyclone model. Subsequent numerical simulations of rapidly developing oceanic cyclones initialized with observations produced frontal configurations consistent with those in idealized models, suggesting shortcomings in the polar-front cyclone model.

As enumerated in Shapiro and Keyser (1990), the numerical studies indicate: 1) the weakening of the baroclinicity defining the cold front in the vicinity of the center of the cyclone during the early stages of cyclogenesis, referred to as "frontal fracture"; 2) the westward migration of the warm front (in a system-relative sense) toward the northerly flow to the rear of the intensifying cyclone; and 3) the formation of a warm-core seclusion in the mature cyclone, consisting of cool air initially from within the pre-existing baroclinic zone on which the cyclone forms, rather than from the warm side as in the polar-front model (Fig. 1IV). It is noteworthy that none of the numerical simulations replicates the classic occlusion process of the cold front catching up to the warm front and forcing warm air aloft.

A four-stage conceptual model inspired by numerical simulations of the evolution of midlatitude cyclones and verified in part with data from recent field studies of oceanic cyclones [e.g., ERICA, the Experiment on Rapidly Intensifying Cyclones over the Atlantic (Hadlock and Kreitzberg, 1988)], proposed by Shapiro and Keyser (1990), is reproduced in Fig. 8. The four phases of frontal development are: 1) a broad, continuous baroclinic zone on

which cyclogenesis begins; 2) the frontal fracture in the vicinity of the cyclone center and the intensification of the cold and warm fronts; 3) the so-called frontal T-bone and bent-back warm front characteristic of the middle period of cyclogenesis; and 4) the seclusion stage within the polar air behind the cold front, characteristic of a mature midlatitude cyclone. The depiction shows two airflows corresponding to low-level jets in the pre-frontal warm air and just poleward of the warm front, consistent with the warm and cold conveyor belts of the cyclone model based on relative-flow isentropic analysis (Fig. 5). It remains for future research to verify the details and representativeness of this conceptual model, as well as to elucidate the associated vertical structure of the frontal zones and airflows (i.e., integration with the depiction in Fig. 4).

CONCLUDING REMARKS

This review has sketched the evolution of conceptual models of frontal structure and its relationship to cloud and precipitation systems since the introduction of the Norwegian polar-front cyclone model to synoptic meteorology. Progress in describing and understanding the structure and dynamics of frontal zones during this century has been tied closely to technological innovations leading to advances in observing and modeling capabilities, a pattern noted by Reed (1977). The Norwegian polar-front cyclone model followed the introduction of surface observing networks; conceptual models incorporating the vertical structure of fronts, including their relationship to the tropopause, followed the development of upper-air observing networks; the relative-flow isentropic analysis models followed the introduction of satellites and radars; and the revision to the polar-front cyclone model described here is a consequence of attempting to reconcile theoretical predictions, based upon application of state-of-the-art computing technology, with fragmentary mesoscale observations derived from instrumented aircraft. The current revolution in remote-sensing technology, coupled with seemingly inexorable advances in supercomputers, promises ample opportunity to consider extending and refining contemporary conceptual models of frontal systems.

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FIGURES

Fig. 1. The Norwegian polar-front cyclone model of Bjerknes and Solberg (1922).

Fig. 2. Conceptual models of fronts in the vicinity of the tropopause: (a) Bjerknes (1932); (b) Palmén (1933); (c) Bjerknes and Palmén (1937); (d) Nyberg and Palmén (1942) and Berggren (1952); (e) Newton (1954) and Reed and Danielsen (1959). From Shapiro and Keyser (1990).

Fig. 3. Schematic diagram of a contemporary model for analyzing upper-level fronts and tropopauses synthesizing aspects from the Nyberg-Palmén-Berggren and the Newton-Reed-Danielsen models (Figs. 2d and 2e). Solid lines denote frontal and tropopause boundaries; dashed line depicts the boundary of cyclonic shear zone in the lower stratosphere. From Keyser and Shapiro (1986).

Fig. 4. Schematic depiction on a surface of constant pressure of the propagation of an upper-level jet-front system through a midlatitude baroclinic wave: (a) formation of a jet-front in the confluence between mid- and high-latitude (polar and arctic) flow regimes; (b) jet-front situated in the northwesterly flow inflection of amplifying wave; (c) jet-front at the base of the trough of fully developed wave; (d) jet-front situated in the southwesterly flow inflection of damping wave. Geopotential height contours, thick solid lines; isotachs, thick dashed lines; isotherms, thin dashed lines. From Shapiro (1983).

Fig. 5. Schematic depiction of airflow through a mature midlatitude cyclone. From Carlson (1980). (See Fig. 9 of reference for detailed explanation of figure.)

Fig. 6. Schematic diagram depicting airflow pattern characteristic of an anafront, where the warm conveyor belt (indicated by bold arrow with stippled shading) is undergoing rearward-sloping ascent in the warm air overlying the frontal zone and the cold air is descending beneath it (indicated by dashed lines): (a) plan view; (b) vertical cross section along line *BA* shown in (a). Flow patterns are indicated relative to moving frontal system; LLJ denotes the axis of the low-level jet in (b). From Browning (1985).

Fig. 7. Schematic diagram depicting airflow pattern where the warm conveyor belt (bold arrow with stippled shading) is undergoing forward-sloping ascent ahead of a katafront before rising above the cold conveyor belt (dotted arrow) poleward of the warm front. Midtropospheric air characterized by low wet-bulb potential temperature (dashed arrow) is overrunning the cold front and generating potential instability in the upper regions of the warm conveyor belt. The vertical cross section in (b) is taken along line *AB* indicated in the plan view shown in (a). Flow patterns are indicated relative to the moving frontal system. From Browning (1985).

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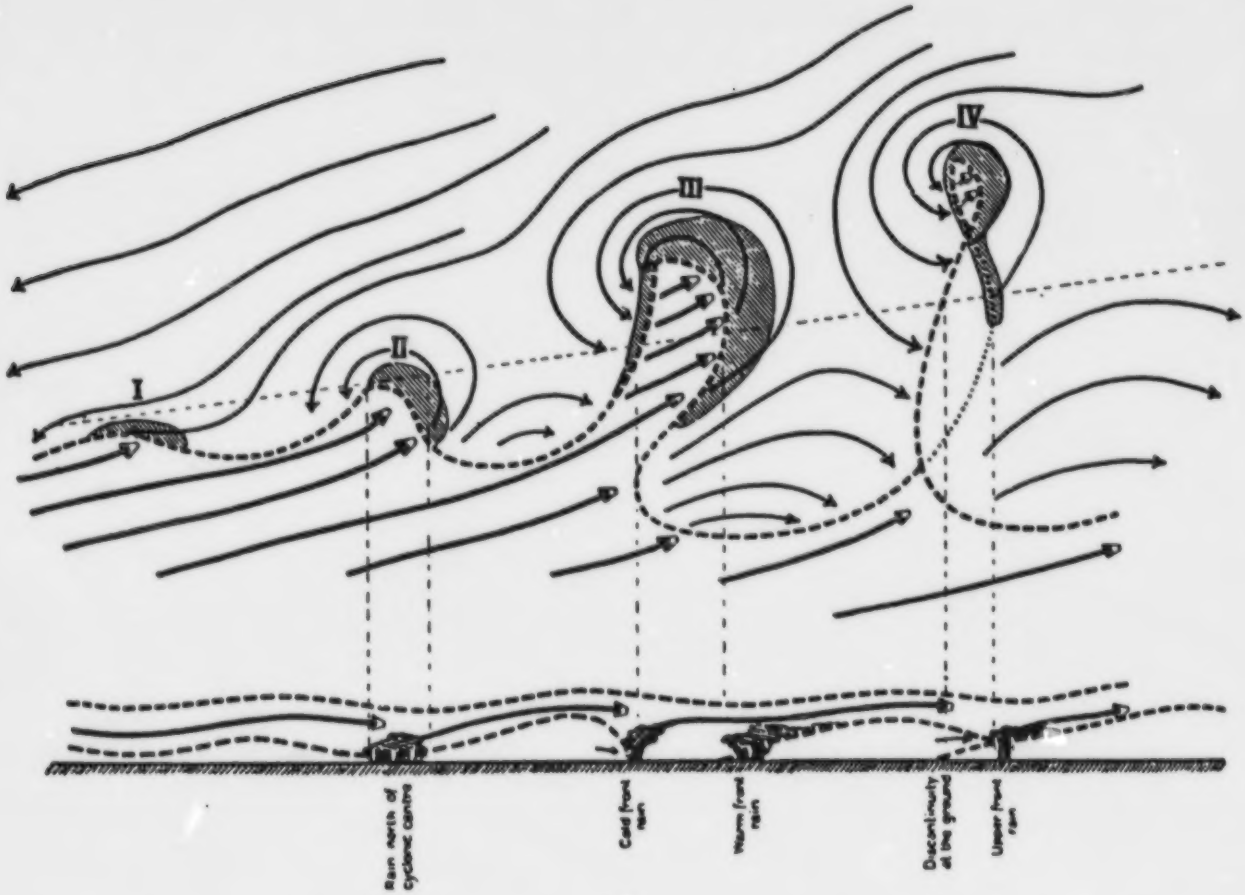

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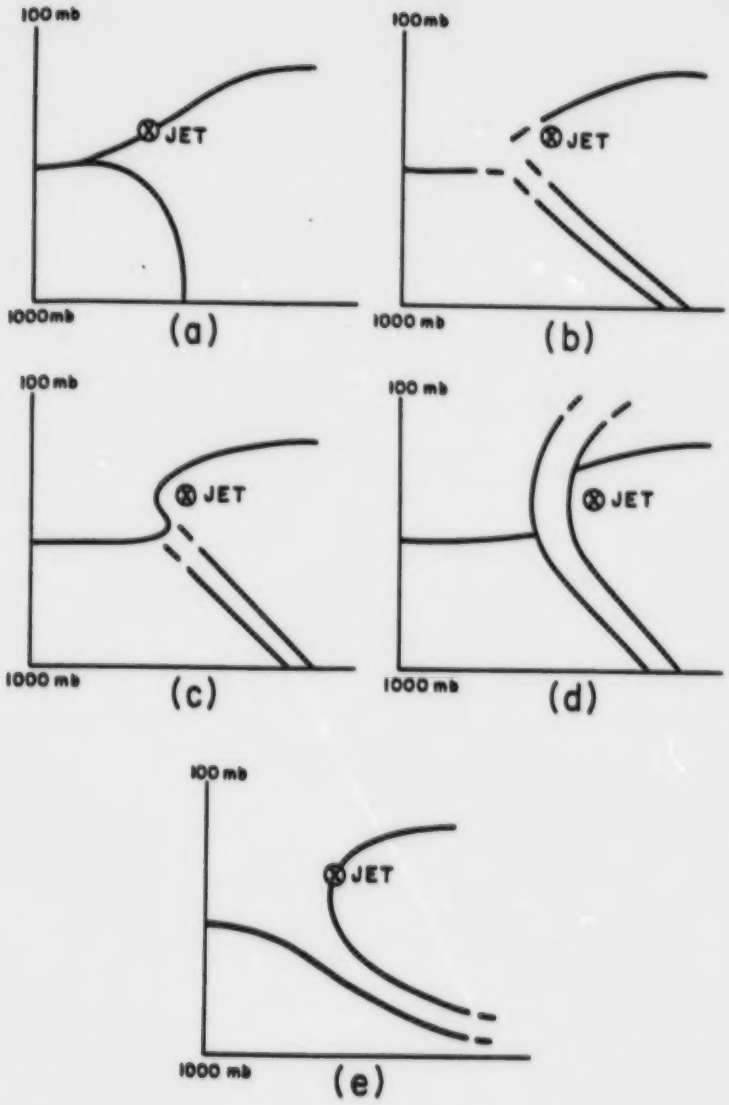

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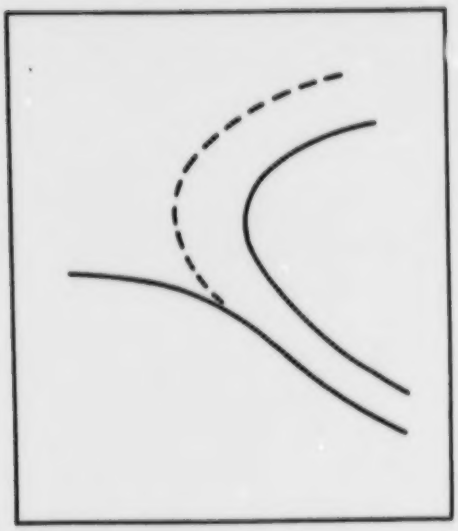

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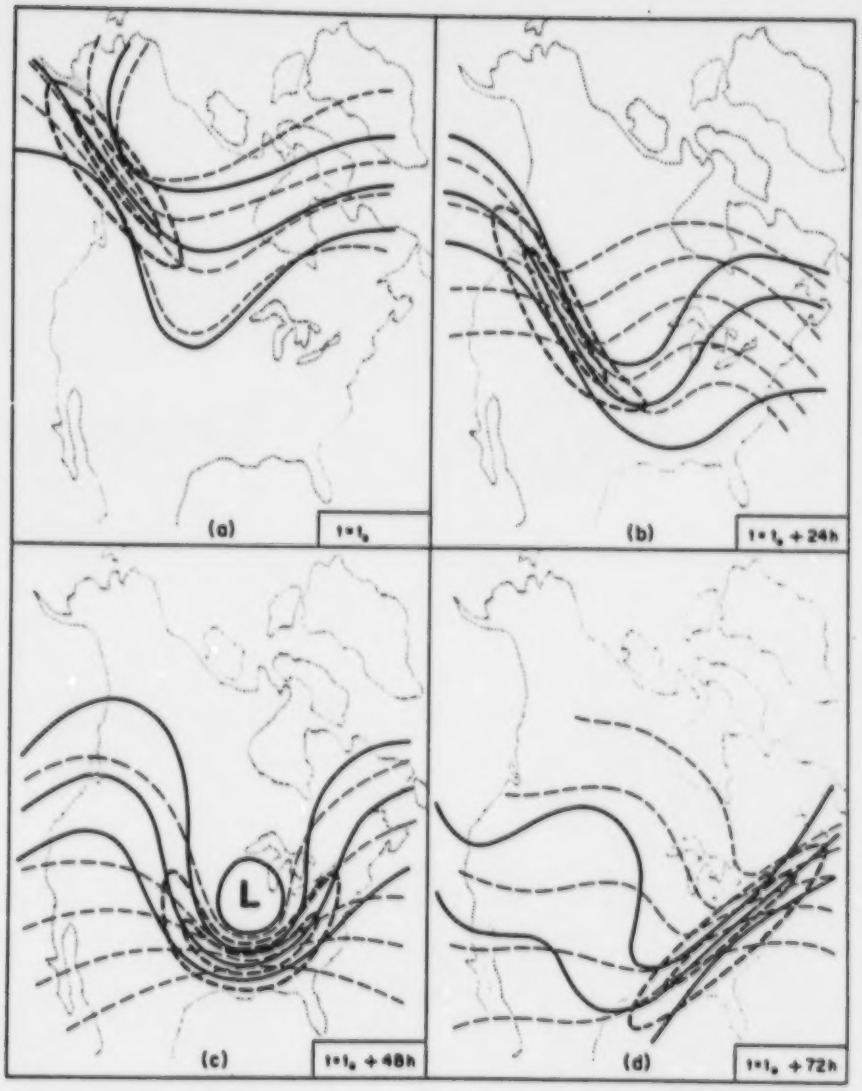

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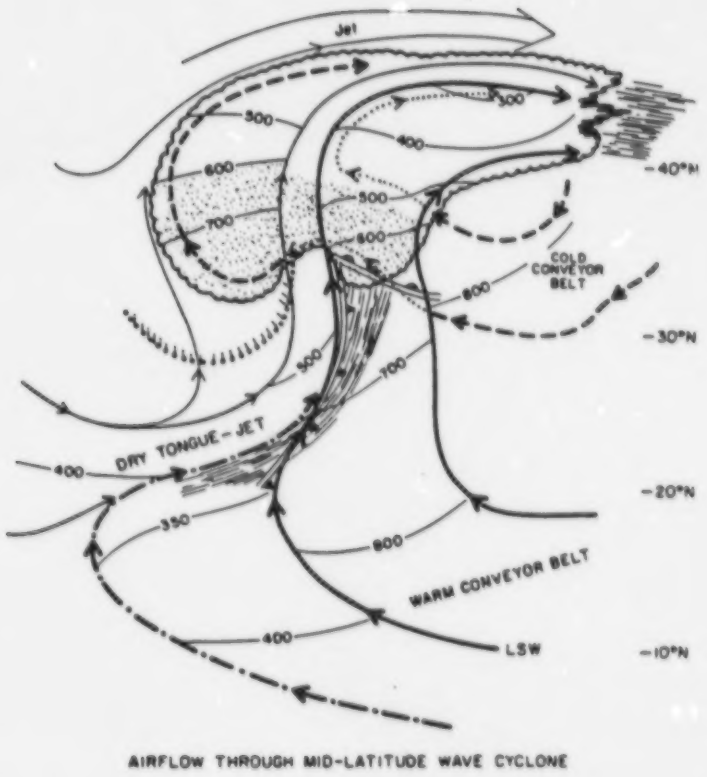

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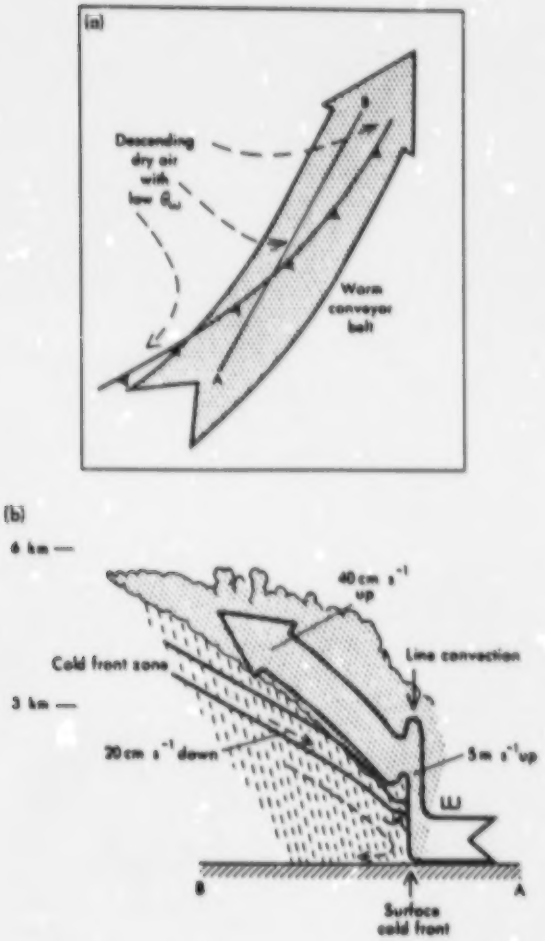

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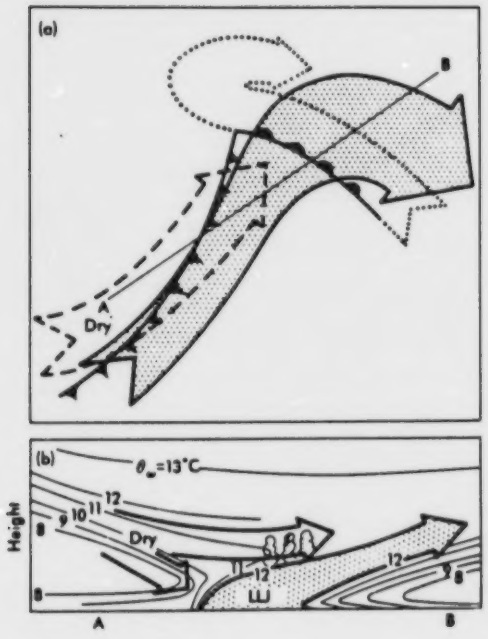

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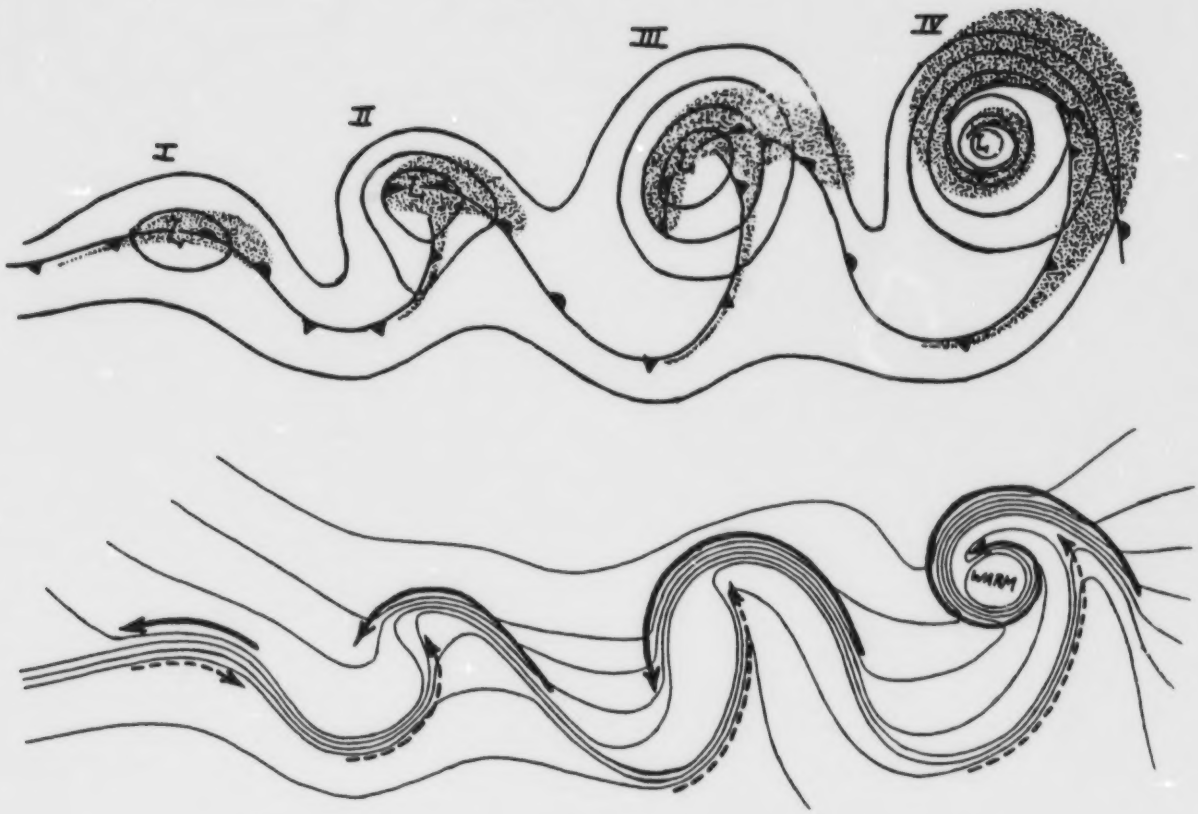

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A Demonstration Network of Wind Profilers

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ABSTRACT. A 30-site demonstration network of wind profiling radars will be installed in the central United States. A central facility will monitor their operation, and process the raw data into high quality hourly averaged wind profiles for dissemination to the National Weather Service. The operation of the network and meteorological impact of the data are described.

RESUMÉ. Un réseau expérimental de 30 sites équipés de profileurs de vent sera installé dans le centre des États-Unis. Une centrale contrôlera l'opération du réseau et convertira les données brutes en profils de vents de haute qualité à toutes les heures qui seront transmis au "National Weather Service". Le fonctionnement du réseau et l'impact météorologique de ces données sont décrits.

INTRODUCTION

The wind profiler is a Doppler radar capable of measuring profiles of atmospheric winds from near the earth surface to above the tropopause. The National Oceanic and Atmospheric Administration (NOAA) of the U.S. Dept. of Commerce will deploy a network of 30 wind Profilers in the central U.S. during 1990-91 (Fig. 1). This 30-site demonstration network will be used to assess the utility of the wind profilers in an operational environment and help define operational requirements for a possible national network.

BACKGROUND AND EVOLUTION

The wind profiling technique developed from sensitive ionospheric radars operating two decades ago. It was found that minute variations in atmospheric density caused scattering of radio waves. The resulting fluctuations of the index of refraction are used as a tracer of the mean wind. Using the Doppler effect, wind profilers measure radial velocities in three pointing directions, typically north, east, and vertical. With simple trigonometry, horizontal wind speed and direction are computed at each measurement height.

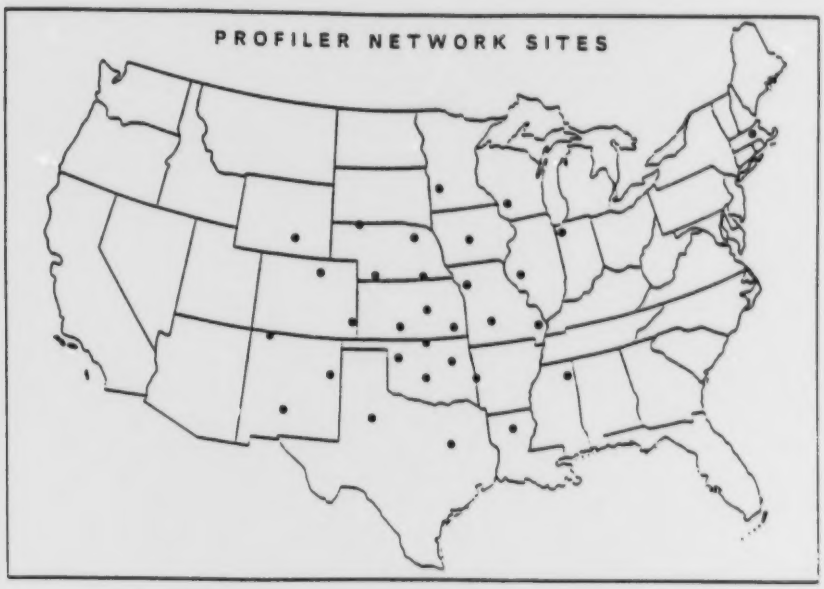

Fig. 1. Location of wind profiler demonstration network sites.

During the past 10 years, NOAA's Environmental Research Laboratory (ERL) in Boulder, Colorado has operated wind profilers at three different frequencies (50, 404, and 915 MHz) to examine measurement capabilities at each frequency (Hogg et al., 1983; Strauch et al., 1984). Limitations exist at each frequency due to frequency allocation or meteorological constraints. The frequency of 404.37 MHz (within the present meteorological aids band of 403-406 MHz) was chosen as the optimum frequency for a demonstration network of wind profilers.

METEOROLOGICAL/HARDWARE REQUIREMENTS

Meteorological requirements had previously been identified by the user community. Hardware/software specifications designed to meet these requirements were then defined by ERL. Major meteorological requirements for the wind profiler include:

- Operate in nearly all weather conditions
- Provide wind data automatically and continuously with unattended operation
- Be suitable for widespread use in networks
- Accuracy of orthogonal components to better than 1 m/s
- Height resolution of 250 m below 300 mb, and 1 km to 100 mb
- Temporal resolution of 60 min. for profiles to 100 mb.

Stringent requirements were placed on the system reliability due to the profilers' remote, unattended operation. Mean-time-between-failure (MTBF) was specified to be six months. A low sidelobe antenna was also specified to minimize return signals from nearby, lower altitude targets. This reduces the chance that the true clear-air signals above the profiler would be dominated by strong return signals from nearby thunderstorms in a sidelobe.

In 1986, NOAA selected the Unisys Corp. to develop and manufacture wind profiler systems to NOAA specifications. This represents a major technology transfer from research and development to industry (Chadwick and Hassel, 1987). Two prototype wind profilers have been built by the Unisys Corp. and accepted by NOAA. Production has begun on 30 additional units at this time, with delivery of the first unit expected in March 1990. The scheduled installation rate is 2-3 profilers per month. One acre of land has been leased and prepared at each site.

PROFILER OPERATION

Each system will operate on standard 115/230 volt, 50-60 Hz commercial power. Profiler sites will typically be located in rural areas. No backup generator or uniterruptible power supply (UPS) will be used; therefore downtime due to occasional power failures is to be expected. Each site will use power line filters and transient suppressors for lightning protection. The equipment is designed to automatically restart after a power failure, as long as a hardware failure has not occurred. Unisys is using a low-voltage solid state transmitter, capable of producing approximately 16 kilowatts of peak power, or approximately 1,500 watts of average power.

The profiler generates three sequential beam positions, one vertical and two oblique. Winds are measured by the profiler every 250 m (approximately 800 ft) in the vertical from a minimum height of 500 m (1,600 ft) above ground level (AGL) to a maximum height of 16.25 km AGL (approximately 53,000 ft or about 100 mb). See Fig 2. The profilers operate in two separate modes; a low mode or a high mode. The low mode measures winds from 500 m above the ground to a maximum of 9.25 km AGL. The high mode measures winds with reduced resolution from 7.5 km to a maximum of 16.25 km AGL. Data acquisition (estimates of the signal power, radial velocity, and spectral width) for all sample heights in each mode and beam position takes 6 minutes. These data are then transmitted via a commercial satallite link to a central processing hub.

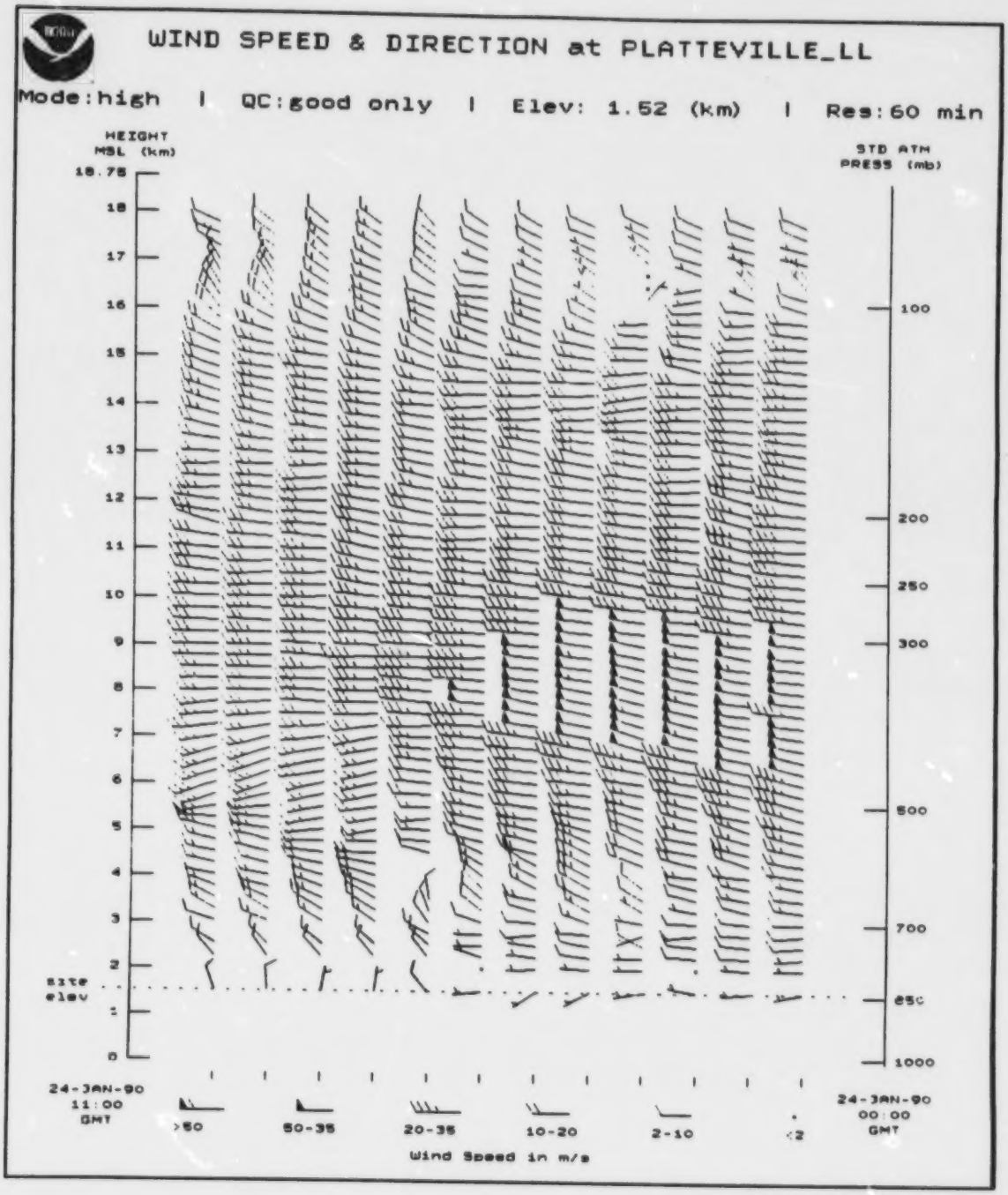

Fig. 2. Typical hourly averaged winds measured by the Platteville Prototype. A weak frontal passage is evident in the lower troposphere and ridge axis passage at mid-levels.

PROFILER CONTROL CENTER

The central processing hub, located in Boulder, Colorado, is called the Profiler Control Center (PCC). Hourly averaged wind profiles are computed for each site and subject to quality control checks (Brewster and Schlatter, 1988). These high quality profiles are then transmitted to the National Weather Service (NWS) for dissemination to their forecast offices via AFOS (Automation of Field Operations and Services).

The PCC will monitor the operation of the profiler network, responding to faults and initiating maintenance visits by NWS electronics technicians. The PCC will also be responsible for monitoring SARSAT (Search and Rescue Satellite-Aided Tracking) satellite passes. When the profilers are transmitting, they interfere with SARSAT equipped satellites passing nearly overhead. The PCC will generate transmitter inhibit times for each profiler site when these satellites are scheduled to pass nearly over a profiler site. Approximately four turnoffs per day can be expected at each site, with a duration of five minutes each. These transmitter inhibit times have minimal impact on the hourly averaged winds.

FORECASTER TRAINING

The Program for Regional Observing and Forecasting Services (PROFS) has developed a training package about wind profiler data for the NWS. It is designed to aid the meteorologists in understanding and using this new technology. The training package consists of four training manuals and accompanying videotapes. In addition, PROFS is hosting five specialized workshops in Boulder to give NWS forecasters from different regions a thorough introduction to the new data.

ASSESSMENT

The NWS will assess the operation of the network through 1992 (Smith, 1988). This assessment has two goals:

- Use the operational information from the wind profilers in an operational environment to better understand the ways the data may be used to improve NWS operational forecasts and services

- Assess the system characteristics of the wind profilers, both individually and in networks, to determine those characteristics required for a fully operational national network.

Activities to meet these goals include development of applications techniques for local forecast offices to use in mesoscale forecasting. This will include the capability to compute hourly profiles of divergence and vorticity from a triangle of profilers. In addition, the National Meteorological

Center (NMC) will incorporate profiler data into operational forecast models. The impact of these data on the models will be investigated. Finally, the reliability, maintainability, height coverage, operating costs, etc., of the individual profilers and the network as a whole will be assessed.

SUMMARY

NOAA will install a 30-site demonstration network of wind profiling radars in the central U.S. during 1990-91. A central facility (the PCC) will process the raw data into high quality hourly averaged wind profiles for dissemination to NWS forecast offices. These data should aid short-range weather forecasting affecting business, aviation, recreation and agriculture. The utility of the network will be assessed in an operation environment and will help define requirements for a possible national network.

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OPERATIONAL ASSESSMENT OF THE LOW-LEVEL WIND STRUCTURE

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ABSTRACT

The structure of the low-level tropospheric winds (below 700 mb) is of prime importance for the operational forecaster (strong synoptic winds, cold air injections, synoptic fronts, identification of low-level jets and convergence lines, mesoscale circulations, etc...). Although working primarily with synoptic scale features, forecasters have to deal with mesoscale phenomena using an often inadequate observing network. The evaluation of low-level wind structure relies strongly on analyses and prognoses based on upper air wind data. Methods and accuracy of the rawinsonde wind measurements are reviewed with a special emphasis on the problems of accurate identification of low-level jets. These are frequently underestimated because of the inherent oversmoothing of the wind data. The impact of new tools that are now (or will be) available to the operational meteorologist (doppler radar, wind profiler, improved aircraft reports, satellite winds, new model outputs, etc..) in the assessment of the low-level wind structure is examined. For instance, the analysis of doppler velocity measurements can provide a detailed description of mesoscale low-level wind fields in real time. The use of a new scale of conceptual kinematic models to interpret the wind data is discussed along with the training and education needs required in light of the introduction of these new tools in the operational field.

RÉSUMÉ

La structure des vents dans les bas-niveaux (en-dessous de 700mb) est très importante pour le météorologiste opérationnel (vents forts synoptiques, injections d'air froid, fronts synoptiques, identification des courants-jet de bas-niveaux et des lignes de convergences, circulations à la méso-échelle, etc...). Même s'ils travaillent surtout avec des structures à l'échelle synoptique, les météorologistes doivent régulièrement affronter des phénomènes à la méso-échelle avec un réseau d'observations inadéquat. La structure des vents dans les bas-niveaux est évaluée surtout à partir des données de vent du réseau synoptique de radiosondages. Les méthodes ainsi que la précision de ces mesures seront discutées particulièrement en ce qui a attrait à l'identification des courants-jet de bas niveaux. Ceux-ci sont fréquemments sous-estimés dû au lissage excessif inhérent à la méthode d'évaluation des vents de radiosondages.
L'impact de nouveaux outils (radar doppler, profileur de vent, vent obtenu des satellites, vents d'aéronefs) dans l'évaluation de la structure des vents dans les bas-niveaux sera examiné. Par exemple, l'analyse des vents doppler peut fournir une description détaillée du champ de vitesse horizontal à la méso-échelle. L'utilisation de nouveaux modèles conceptuels pour interpréter les champs de vents seront discutés ainsi que les besoins de formation et d'éducation nécessaires à la lumière de l'introduction de nouveaux outils dans le contexte opérationnel.

1. INTRODUCTION

The structure of the low-level tropospheric winds (below 700 mb) is of prime importance for the operational forecaster. Synoptic wind features are generally well resolved by the current observation network and are also well forecast (strong synoptic winds, cold air intrusions, synoptic fronts, etc..). Although working primarily with synoptic scale features, forecasters have to deal with mesoscale phenomena using an often inadequate observing network.

There is a wide range of meteorological conditions for which the detailed assessment of the low-level wind structure is important at a sub-synoptic scale. The low-level jet is an intense (>15m/s), narrow, quasi-horizontal current of wind that is associated with strong vertical shear. The zone of relatively strong jet frequency extends to between 1 and 1.5km above the ground (Bonner, 1968). The role of low-level flow in the life cycle of convective systems is a classical example of the importance of the operational evaluation of the low-level jet. A primary clue for forecasting convection and convection related weather lies in the characteristics of the low-level inflow. The low-level jet rapidly transports heat and moisture toward the convective region and interacts with the upper-level jet to create a region of convective instability within which severe weather can occur (Uccellini, 1979). Studies of mesoscale convective systems have shown that a dependable source of low-level moisture is critical in their development and sustainment (Tollerud et al., 1988). The extent of the veering of the winds with

height has also been shown to be critical in severe storms development.

The assessment of convergence lines is also vital in some cases. The organisation and movement of severe storms is often influenced by strong low-level convergent features rather than by upper level winds. Mesoscale convergence lines play a major role in determining where and when storms will form (Wilson et al., 1986). Stationary convergence lines are often the site of new thunderstorm development. Since the depth of the convergence is typically 1km or less, it is vital to monitor winds close to the ground (Schlatter, 1988). In snowstorms, the presence of bands of enhanced precipitation can be related with mesoscale convergence along with frontal or orographic lifting. Also, the development of the low-level jet has been shown to increase significantly the moisture transport into the region of heavy snowfall (Uccellini et al., 1987). At a smaller scale, the assessment of the airflow into precipitation systems is very useful in short range forecasting.

Low-level wind maxima are also of operational interest because of their effects upon operations involving weather. Joseph (1986) has reviewed the meteorological conditions conducive to, or associated with low-level aircraft turbulence and wind shear. Other examples include the evolution of forest fires and the evolution of air trajectories for pollutant transport. Finally, the forecaster has to deal with a variety of other mesoscale circulations including lake/sea breezes, drainage flows, flows influenced by orography, nocturnal jets, etc... Ultimately, the higher resolution operational numerical models require upper wind and temperature data at a vertical scale which is smaller than the current one.

Therefore, it is important that the forecaster evaluates the different aspects of the low-level wind structure in real time. However, the existing network of surface reports and radiosonde observations often provides only sketchy details of mesoscale wind circulations.

2. CURRENT OPERATIONAL EVALUATION OF LOW-LEVEL WINDS

The operational evaluation of the winds in the low-levels is currently done using the synoptic surface and upper air data through inspection of the forecaster's analysis and the objective synoptic analysis fields (850 and 700 mb charts). A more detailed analysis of vertical structure of the wind is done with the rawinsonde wind observation (wind estimation at each thousand feet or so) by analysis of the hodograph. Also, computer analysis of the wind data can highlight interesting and useful features in real time: height and intensity of the low-level and high level wind maxima, streamline analysis, probable trajectories of thunderstorm cells, etc...

Model outputs contribute significantly in the forecasting of low-level winds. Products such as the low-level wind maximum chart, the forecast surface winds (MOS and others) and the forecast upper winds (FD's) are used in real time by the forecaster. Other valuable sources of data include aircraft reports (pireps) which are very useful in confirming turbulence and wind shear, non-synoptic local pibal soundings and estimation of the winds through satellite analysis. The tracking of precipitation echoes on conventional radar is also helpful in determining the low-level wind field.

The forecaster uses experience and pattern recognition techniques along with the tools at hand to produce the low-level wind forecast. His analysis and prognosis relies strongly on upper air wind data which are usually obtained from the synoptic rawinsonde observation network.

3. RAWINSONDE WIND ESTIMATION

Rawinsonde measurements are essentially line samples along a slant path through the atmosphere. Owing to the limited sample volume in time and in space, the representativeness of the sounding is critical. The displacement of the radiosonde, which is typically tens of km horizontally from its lauching point, is another aspect. Studies show that measurement errors are confined to an acceptably low level when considering analysis of temperature, geopotential and wind fields on a synoptic scale. The wind speed and direction measurements reflect the synoptic scale geostrophic flow pattern and are representative of the ambient atmosphere (Kitchen (1989), Hoehne (1980), Hollingsworth et al.(1986)). However, the operational upper air network has a poor spatial and temporal resolution to assess sub-synoptic scale features. Therefore, the measurement adequacy is not only limited by the performance of the measurement system but also by the representativeness of the data. Although present in synoptic scale problems, this issue is a crucial one at smaller scales especially when assessing mesoscale wind features.

It is generally accepted that rawinsonde wind measurements are accurate to ±1 m/s (<10m/s, ±10% for winds >10m/s) and ±2° which agrees with WMO standards. However there is a lack of recent studies on the subject. In fact, a workshop[1] focussing on the accuracy of radiosonde systems was recently held in order to aid the future development and direction of upper air systems. Moreover, published studies on the performance of rawinsondes in the evaluation of low-level jets and wind shear are almost inexistant. There are a few studies which evaluate their performance in strong wind shear cases but only for mid and high levels and especially at jet stream level (Salmela et al., 1959).

In some conditions, wind measurements underestimate the true wind. At low elevation angles (<10°), interference by ground reflected signals produce large errors in the measurement of elevation angles. Also, the averaging techniques[2] tend to smooth sharp wind gradients as in the case of jet streaks (Golden 1986). But, the smoothing and fitting techniques generally produce wind data which are appropriate to conventional synoptic analysis (Danielson et al., 1967).

Rawinsonde data provide spot samples of the horizontal winds. Fine scale wind features often pass undetected between upper air stations. This is especially true in the case of a low-level wind jet where the upper air data, because of its relatively poor spatial and temporal resolution, will likely not detect the narrow jet core. Moreover, in the case where the sounding would pass through the jet core, the inherent smoothing techniques can underestimate significantly its intensity. To a lesser extent, this is also true when radiotheodolites with ranging systems are use with transpondersondes (18 of the 32 canadian upper air have them). Published studies on the subject are scarce but some specialists in the field estimate that in these cases the measured wind is up to 20 to 30% weaker than the true wind.

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[1] Upper Air Measurement and Instrumentation Workshop, Wallops Island, Virginia, 14-16 November 1989

[2] Radiosonde data is sampled at a rate of around 50 times/sec. Using least square fitting techniques, the data is determined for each minute of the sounding. Additional smoothing is performed by applying a linear average to the data when the elevation angle <12°. Finally, a third smoothing is done as each one-minute data is averaged over a 2 minute interval (4 min. interval above 7 km and 6 min. above 20 km). At this stage, the operator can modify the data if he sees any spurious or non-uniform features in the one-minute averaged data.

The underestimation of the wind in these specific cases is, in fact, due to a number of problems. First, the smoothing is done to produce wind data at a synoptic scale and not for mesoscale purposes, which includes low-level jets. Second, at low elevations, ground echoes and side lobe returns can cause non-uniformities in the data. This contamination is added to the true non-uniformity of the wind field in the case of low-level jets. Third, the operator of the rawinsonde sytem can modify the data if non-uniformities are apparent on the displayed elevation and azimuth angles, range and height data. He can also do this through inspection of the ground position plot of the radiosonde to visualize the non-uniformities. This process requires experience and the end result is to produce smooth and uniform wind fields. Also, the operator is quite knowledgeable about the high level jets (jet stream) and is not surprised to observe wind maxima at that level. However, since low-level jets are infrequent and information on the subject is scarce, the operator will generally oversmooth these wind features.

Therefore, current rawinsonde wind measurements are generally appropriate at the synoptic scale. However, mesoscale wind circulations and especially wind maxima and low-level jets are not well identified by the current operational rawinsonde network.

4. IMPACT OF NEW TOOLS IN WIND ASSESSMENT

As briefly discussed in the last section, there are doubts that the existing upper air measurement system or any balloon-borne system can provide measurements on the smaller time and space scales necessary for accurate and reliable mesoscale low-level wind assessment. This is why remote sensing devices, which have high temporal resolution and also have automation capabilities, can resolve part of the problem.

The King City doppler radar has been part of the operational program at the Ontario Weather Center since the summer of 1985. The benefits of doppler radar as a tool for observing summer severe convective storms are well documented. However, a wide range of other operational applications in different seasons and synoptic situations can significantly help the meteorologist in his assessment of the low-level wind structure. Crozier et al. (1988) give an overview of these applications. Experience has shown that the analysis of doppler velocity measurements can provide a detailed description of mesoscale low-level wind fields in real time. Additionally, we observe in some cases that rawin observations are underestimated when compared to the high resolution wind field observed by doppler radar. This agrees with the inherent synoptic smoothing of the rawinsonde wind measurements as discussed in the previous section. Detailed analysis of this problem has not been done, but, for instance, specific examples include the case of the 17 Sept. 1987 (Joe et al., 1987) and 17 July 1986 (Joe et al., 1990) where the intensity of the wind jet maxima was underestimated by 40 to 50% when compared with the King City doppler wind measurements. Other applications include the detailed identification of frontal surfaces, the evolution of freezing rain situations, lake effect snowsqualls, identification of severe gust fronts and downbursts, etc... Moreover, doppler wind analysis can show detailed kinematic structures of the order of tens of kilometers. This can significantly improve our understanding of the airflow into mesoscale precipitation systems in real time and the relationship between jet evolution and system intensification (Joe et al., 1990).

Other tools will gradually move into the operational field and improve our assessment of the low-level winds. Wind profilers with their high temporal resolution will greatly enhance our wind assessment in real time. The Wind Profiler Demonstration Network (30 profilers in the central US) will help define the operational requirements and applications (Chadwick, 1988). Generally speaking, the US STORM project will have a direct impact on wind assessment as higher resolution upper air data are obtained. Automation of aircraft weather data reports will also have an impact in wind assessment. Aircrafts equipped with ACARS[3] can automatically relay wind data through satellite communication links. The ACARS system provides independent data source that can complement other wind data for constructing wind field analysis and vertical soundings during aircraft ascents and descents. Winds derived from satellite data analysis still have some accuracy problems and are mainly directed to mid and high-level wind estimation.

The introduction of wind measurements at a higher resolution and accuracy into the objective analysis(OA) scheme will also have an impact on the quality of model wind outputs. For instance, within a year or so, CMC will incorporate rawinsonde data in the OA at 50 mb intervals in the lower troposphere as opposed to using only mandatory level data which is currently done. Better evaluation of low-level jets should improve model performance in the development of explosive winter storms (Mailhot et al., 1989). However, there are still many challenges ahead in order to incorporate profiler and doppler radar data into mesoscale models (Walko et al.(1984), Uccelini(1987),Kuo et al.(1989)).

5. CONCLUSION

The meteorologist has to evaluate different aspects of the low-level wind field in real time for a wide range of synoptic and, especially, mesoscale meteorological conditions. In order to do so, he relies strongly on data obtained from the synoptic rawinsonde network. However, as we have discussed, the existing network, because of its poor spatial and temporal resolution, provides only sketchy details of mesoscale wind circulations. Moreover, the inherent smoothing techniques of the rawinsonde measurements, which are generally appropriate to the synoptic scale, tend to underestimate the intensity of mesoscale wind features. Detailed studies should be initiated on the impact of the current smoothing techniques and on the future operational (and numerical models) needs in the accuracy and resolution of rawinsonde wind data.

The impact of new tools (doppler radar, wind profilers, automated aircraft reports (ACARS), new model outputs, etc...) in the operational assessment of the low-level winds is (or will be) very significant. Not only will they provide improved short-term forecasts but they will enhance the operational forecaster's understanding of mesoscale meteorological phenomena. With detailed profiles of wind, temperature and humidity in the lower troposphere forecasters could surely improve nowcasting and short range extrapolations of most weather conditions considered hazardous (Schlatter, 1988).

Mesoscale wind fields are commonly observed on doppler radar imagery. These images are difficult to interpret and require the use of a new scale

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[3] Arinc(Aeronautical Radio Inc.) Communications, Addressing and Reporting System.

of conceptual models which are still evolving through operational experience, extensive field programs and numerical modelling studies (Joe et al., 1990). Models of synoptic-scale features are generally better developed than those of mesoscale phenomena since they can often be understood in terms of conventional surface and upper air data that have been available for decades. On the other hand, most forecasters have had little opportunity to gain experience with concepts of mesoscale phenomena (Bader et al.,1988). Therefore, in light of the introduction of new tools in low-level wind assessment, there is a need for more training and education in the meteorological interpretations of radar and satellite imagery. As part of this training, there is a need for a better conceptual framework within which to interpret the imagery and other wind data data sources (Browning, 1986).

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THE QUALITY OF MOORED BUOY WINDS

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ABSTRACT

The Atmospheric Environment Service has recently established a network of moored buoys in the Northeast Pacific, Great Lakes, and North Atlantic. These buoys make essentially the same measurements using the same sensors and hull types as those of the U.S. National Data Buoy Center (NDBC). Recently, forecasters have questioned the accuracy of NDBC buoy-reported wind speeds because they are light in comparison with ship-reported winds. Since about 40 percent of U.S. marine warnings are based, at least in part, on these winds, data quality is an important issue.

Several field intercomparisons of buoy winds were conducted to investigate the quality of the observations. Differences between dual anemometers on the same buoy were calculated during tropical cyclones. The speed and direction differences did not grow appreciably with increasing wind speed, and at no time was the speed difference greater than 1 m s^{-1}. This is an excellent result considering that the anemometers are mounted on opposite sides of the centerline and are therefore subject to different instantaneous accelerations. Differences between winds measured at collocated buoys and a buoy moored near a platform were investigated. Standard deviations of speed and direction differences between the two buoys are about 0.7 m s^{-1} and 10°, respectively. Scatterplots show linear relationships with no obvious biases in any range of wind speed or wave height. Therefore, it does not appear that buoy motion or sheltering during high seas is adversely affecting the measurement. Having established the good quality of buoy winds, it is thought that the poor comparison with ship winds is due to differences in anemometer heights, averaging methods, averaging periods, and averaging times.

RESUME

Le Service de l'Environnement Atmosphérique a dernièrement établi un réseau de bouées fixes dans nord-est du Pacifique, sur les Grands-Lacs et sur l'Atlantique nord. Ces bouées prennent essentiellement les mêmes mesures et utilisent les mêmes capteurs que celles du " U.S. National Data Buoy Center (NDBC)". Récemment, les prévisionistes ont remis en question la précision des rapports de vitesse de vents des bouées du NDBC parce que trop faibles à comparer avec les rapports de navires. Puisque 40% des avertissements maritimes américains sont émis en se basant sur ces vents, la qualité de ces données est primordiale.

Plusieurs intercomparaisons de vents de bouées ont été menées pour évaluer la qualité des observations. Les écarts de vitesse et de direction de vents entre deux anémomètres sur une même bouée ont été calculés durant des tempêtes tropicales. Les écarts de vitesse et de direction n'augmentent pas avec la force du vent et, à aucun moment, n'excède 1 m/sec. c'est une excellent résultat si on considère que les anémomètres sont montés sur des côtés opposés et sont donc soumis à des accélérations instantanées différentes. Les écarts entre bouées situées dans un même secteur et une bouée fixée près d'une plate-forme ont aussi été étudiés. Les écarts-types des différences de vitesse et de direction du vent entre les deux bouées sont de l'ordre de 0,7m/sec et de 10° respectivement. Des diagrammes de dispersion montrent des relations linéaires avec aucin biais apparent pour toute force de vent ou hauteur de vague. Il appert donc que les mouvements de la bouées ou l'effet d'abri par mer haute n'affectent les mesures de façon appréciable. La qualité des vents de bouées étant établie, nous pensons que les différences avec les rapports de navires réflètent des différences de hauteur d'anémomètres de même que des différences dans les durées, les temps et les méthodes de faire la moyenne.

1.0 INTRODUCTION

The Atmospheric Environment Service (AES) has deployed moored buoys at 17 locations in the eastern Pacific, Great Lakes, and north Atlantic starting in 1988. The AES started this program because of recommendations made to improve forecasting following an 1984 storm in British Columbia that killed several fishermen. A.C.M. Allen and W.G. Richards (1988) of the AES recently compared winds from a single North Atlantic buoy to nearby ship reports and found important differences. In particular, mean ship wind speeds averaged 1.5 meters per second (m s^{-1}) higher, with the difference being even greater under strong wind conditions. Wilkerson and Earle (1990) noted similar differences in a much larger study involving many moored buoys.

This paper examines field intercomparisons of moored buoy data to discover if buoy motion or sheltering during high seas is degrading wind measurements. Winds measured from different buoy hull types are compared as well as those reported by a Coastal-Marine Automated Network (C-MAN) station on an offshore platform. Though the study is performed on U.S. buoys, the results should be directly applicable to Canadian buoys. The AES uses the same 3-meter discus and 6-meter boat-shaped hulls and the same anemometers as the National Data Buoy Center (NDBC). Descriptions of the hulls and measurements can be found in Hamilton (1986 and 1988). The calibration of the wind sensors is described in Gilhousen (1987). Wind speed and direction are sampled for an 8-minute period on buoys and a 2-minute period at C-MAN stations.

2.0 DUPLICATE SENSOR COMPARISONS ON THE SAME PLATFORM

All NDBC buoys and C-MAN stations have duplicate anemometers. Monitoring data from both sensors is helpful in diagnosing failures in near-real time (Gilhousen, 1988). At any given time, 60 to 75 percent of buoys have both anemometers functioning. Of the buoys that have an anemometer fail, the failure is often not so fatal as to preclude using the data for monitoring the performance of the working anemometer. For example, worn bearings or a cracked propeller may suddenly decrease wind speeds 15 to 30 percent. Thereafter, the difference between the two speeds is roughly constant.

During 1985, tropical cyclones passed within 110 kilometers (km) of six NDBC buoys and four C-MAN stations. Eight of these stations had both anemometers in working order throughout the passage of the storms. These stations are listed in Table 1. In order to assess how data compared from these duplicate anemometers, several weeks of data centered around the passage of these storms were examined. The mean difference, called the bias (B), and the standard deviation of the differences (SD) between duplicate speeds and directions were computed. All buoy stations and all C-MAN stations were grouped separately for various ranges of wind speed to see how well the sensors tracked together with increasing wind speed.

The results for wind speed are shown in Figure 1. Overall, the biases and standard deviations were about the same for buoys as they were for C-MAN stations on fixed platforms. The SD's were well within 1 m s^{-1}. In fact, the greatest single difference between any two anemometers was 1 m s^{-1}. This is an excellent result considering that the anemometers are mounted on opposite sides of the centerline and are therefore subject to different

Table 1. NDBC buoy and C-MAN stations which experienced at least gale force winds from 1985 tropical cyclones and which had dual anemometers.

Station	Location (°N, °W)	Storm Name	Hull Type
41002	32.3 75.3	Gloria	NOMAD
42001	25.9 89.7	Danny	Large Discus
42007	30.1 88.9	Elena	Large Discus
44009	38.5 74.6	Gloria	Large Discus
44012	38.8 74.6	Gloria	Large Discus
ALSN6	40.5 73.8	Gloria	Platform
CHLV2	36.9 75.9	Gloria	Platform
SVLS1	31.9 80.6	Bob	Platform

instantaneous accelerations. The highest sustained wind speed measured by a buoy was 33.0 m s^{-1}, and the highest significant wave height was 14.2 m.

The SD's showed a gradual rise with increasing wind speed, but the SD's increased more rapidly for the fixed platforms than for the buoys. This is a surprising result if buoy motion is suspected to be a significant source of error in wind measurement. For, if that were the case, differences between duplicate sensors located on buoys would be larger than differences between duplicate sensors located on platforms in storm episodes. Perhaps turbulence generated by the structure and navigation gear on these fixed C-MAN station platforms is the cause for the greater differences. A more probable explanation is that the shorter, 2-minute scalar averages performed by the C-MAN stations caused larger SD's.

It is also worth noting that in November 1985, Hurricane Kate passed directly over buoy station 42003 in the eastern Gulf of Mexico. Highest sustained winds were measured at 47.3 m s^{-1} with gusts to 58.5 m s^{-1}. At the same time, a hurricane reconnaissance aircraft estimated the surface wind to be 47 m s^{-1}. This observation was not included in the previous statistics because the buoy had only one working anemometer.

3.0 BUOY INTERCOMPARISONS

In order to qualify the 3-meter discus buoy for operational use, data from 3-meter buoys were collected at three locations where other NDBC data were also available. One of these locations was in eastern Lake Superior, where a 3-meter discus buoy was moored 3.3 km WNW of a NOMAD moored at station 45004 (47.2°N, 86.5°W). Both buoys had the same onboard processing and were equipped with dual Bendix anemometers located 4.9 m above sea level. Statistics summarizing the differences between all four speeds and directions were computed. These statistics include the correlation coefficient (r), the bias (B), the standard deviation (SD), and the functional precision (FP) where $FP = (B^2 + SD^2)^{1/2}$ (Hoehne, 1977). October 1984 was chosen because several storm episodes occurred during the month. Wind speeds reached 14.7 m s^{-1} and significant wave heights reached 5.0 m.

Table 2 presents the summary statistics for both wind speed and direction comparisons. The FP's for both speed and direction are somewhat greater for the interbuoy differences than the intrabuoy differences. However, the interbuoy FP's are still within 1.0 m s^{-1} and 10°. The interbuoy differences are slightly greater for higher wind speeds. The SD of these differences for wind speeds greater than 7.5 m s^{-1} is 0.88 m s^{-1}, while for speeds less than 4.0 m s^{-1}, the SD is 0.64 m s^{-1}.

Scatterplots were produced in Figure 2 to see if the interbuoy differences are related to wind speed or wave heights. Figure 2 presents the NOMAD speeds versus 3-meter discus buoy wind speeds stratified by wave conditions. Wave heights above 2.5 m appear as asterisks, while wave heights above 0.8 m with dominant wave periods below 4.5 seconds appear as diamonds. NDBC was particularly interested in how the data compared in this category, which signifies "choppy" wave conditions. The 3-meter discus buoy was observed to have greater buoy motion than the NOMAD in these conditions.

Table 2. Summary statistics for wind speed and direction differences between the 3-m discus buoy and the NOMAD buoy in eastern Lake Superior. The sample size is 717 cases. The notation used under the "Comparison" heading refers first to the buoy type, 3M for 3-m discus buoy and N for NOMAD, then to the anemometer number, 1 or 2. Speed differences are in meters per second and direction differences are in degrees.

	Speed				Direction			
Comparison	r	B	SD	FP	r	B	SD	FP
3M1-3M2	0.991	0.476	0.385	0.612	0.982	-4.12	5.57	6.93
N1-N2	0.993	0.272	0.401	0.485	0.903	-5.54	5.03	7.48
3M1-N1	0.955	-0.162	0.784	0.796	0.929	1.41	9.16	9.27

The high and "choppy" wave cases show slightly higher wind speed for the NOMAD than the 3-meter discus buoy. For the high wave cases, B is 0.78 m s^{-1}; while for the "choppy" cases, B is 0.61 m s^{-1}. However, several prominent outliers exist that are not part of either category. These few outliers were all traced to frontal passages that caused a legitimate discontinuity in the wind (Gilhousen, 1987).

Another field intercomparison was performed off the mouth of the Columbia River in Oregon. A 3-meter discus buoy was moored within 5 km of a Large Navigational Buoy (LNB). The LNB is a 10-meter discus buoy operated by the U.S. Coast Guard for navigational purposes and is equipped with NDBC instruments, including anemometers at 13.8 m above sea level. Figure 3 shows a time series plot of wind speeds from all four anemometers. The first two line types shown in the legend are associated with the LNB anemometers. Figure 4 shows the significant wave heights measured by the two buoys. The spike at 0000 UTC on October 14 was the result of a transmission parity error. The wind speeds in Figure 3 track along together well, even during those times when the significant wave height is over 5 m and the waves exceed the anemometer height on the 3-meter discus buoy. Therefore, the average wind speeds do not appreciably decrease when large waves temporarily shelter the anemometer.

4.0 BUOY VERSUS FIXED PLATFORM WINDS

During the fall of 1984, a 3-meter discus buoy was moored 1.3 km NNE of a C-MAN station located on an offshore tower at Chesapeake Light Station, Virginia (36.9°N, 75.7°W). Winds measured on the platform were compared to winds measured by the buoy. The results from Thornthwaite et al. (1965) were used to site the anemometers where airflow disturbances due to the platform would be minimized. The anemometer height on the platform was 33.3 m and on the buoy was 3.6 m. The platform's anemometers were located 5.8 m above the control tower and 11.0 m above the main flight deck. Two anemometers were located on the platform, and only one on the buoy. The method outlined in Eqs. 2-4 of Liu et al. (1979), which assumes a constant flux layer, was used to correct the speeds from both the platform and the buoy to 10 m before any comparisons were made. October 1984 was chosen for the comparisons because of the passage of Hurricane Josephine. Wind speeds reach 19.5 m s^{-1} on the platform and the significant wave heights reached 3.6 m.

A scatterplot shown in Figure 5 compares the speeds measured on the buoy with the speeds measured by one of the platform's anemometers. Some summary statistics are presented in Table 3. Overall, the functional precision, or comparability, between the buoy and platform is 1.0 m s^{-1}. The SD of the difference between the buoy and platform's speeds is about the same as the SD of the difference between the platform's two anemometers. This SD does not increase with higher wind speeds. For wind speeds greater than 8.0 m s^{-1}, the SD is 0.70 m s^{-1}, while for speeds less than 4.0 m s^{-1}, the SD is 0.69 m s^{-1}. Figure 6 shows that the differences between the buoy and platform's speeds are approximately normally distributed. Figure 7 shows a time-series plot with platform speeds labeled as station CHLV2 and the buoy's speeds labeled as station 44010. Both speeds track together reasonably well. Mesoscale peaks and valleys in the wind are measured well by the buoy, despite significant wave heights of up to 3.6 m.

The only disturbing point is that buoy speeds are lower than the platform speeds for high wind speed events. This is most likely the result of the difference in averaging methods. The buoy's speeds were vector averaged, while the platform's were scalar averaged. Field comparison of both averaging methods was performed for the same anemometer at buoy station 41001 in March 1984. This comparison is shown in Figure 8. The two averaging methods yield equal results for speeds less than 8 m s^{-1}. For speeds greater than 8 m s^{-1}, the vector averaged

Table 3. Summary statistics for wind speed differences in meters per second between a collocated 3-m discus buoy and a platform. Sample size is 712 cases. Platform 1 refers to the first anemometer on the platform; platform 2 refers to the second.

Comparison	*r*	B	SD	FP
Platform 2-Platform 1	0.992	-0.112	0.500	0.512
Buoy-Platform 1	0.971	-0.592	0.814	1.001

speeds are about 7 percent lower than the scalar averaged speeds. A similar relationship between scalar and vector averaging methods has been observed at a number of stations and in a variety of atmospheric conditions. This result helps to explain most of the bias between the buoy and platform speeds.

5.0 CONCLUSION

Field evaluation of buoy winds document the excellent quality of wind speed measurements. Standard deviations of speed differences between two stations separated by less than 5 km are about 0.6 to 0.8 m s^{-1}. Scatterplots show linear relationships, centered around the diagonal, with no obvious biases between the sensors at any range of wind speed. Little evidence was found that buoy motion or sheltering in high waves hinders wind speed measurements.

The differences between ship and buoy winds are probably due to the following factors:

(1) The differences in anemometer height. All 3-meter discus buoys and 6-meter boat-shaped buoys have an anemometer height of 5 m; ship anemometer heights are typically near 20 m. In light winds and very stable air, 5-m winds should be increased by about 50 percent to adjust to a 20-m wind. In higher speeds, the adjustment factor is more typically 15 percent.

(2) The differences due to vector averaging. Vector averaging of speeds is performed on several NDBC offshore buoys and all AES buoys. As explained earlier, the vector averaged speeds are about 7 percent lower than scalar averaged speeds for speeds greater than 8 m s^{-1}.

(3) The longer 8-minute averaging period for buoys versus manual observing methods for ships. Dischell and Pierson (1986) have documented numerous systematic errors in archived ship reports due to human errors and rounding. Correlation coefficients computed between nearby ship winds are considerably lower than similar correlations between nearby buoy winds.

(4) The limited sampling period of buoy winds. Because buoys sample wind for only 8 minutes, they frequently miss the peak wind. The peak wind can be considerably higher when mesoscale variability is present in intense winter storms, tropical cyclones, or squall lines. NDBC is adding continuous wind capability to overcome this problem on many offshore buoys. The highest 5-second average speed (gust) measured during the past hour is being transmitted in real-time from selected NDBC buoys.

Field evaluation of other meteorological measurements and water temperature is discussed in Gilhousen (1987). An evaluation of directional wave data was performed by Gilhousen (1989).

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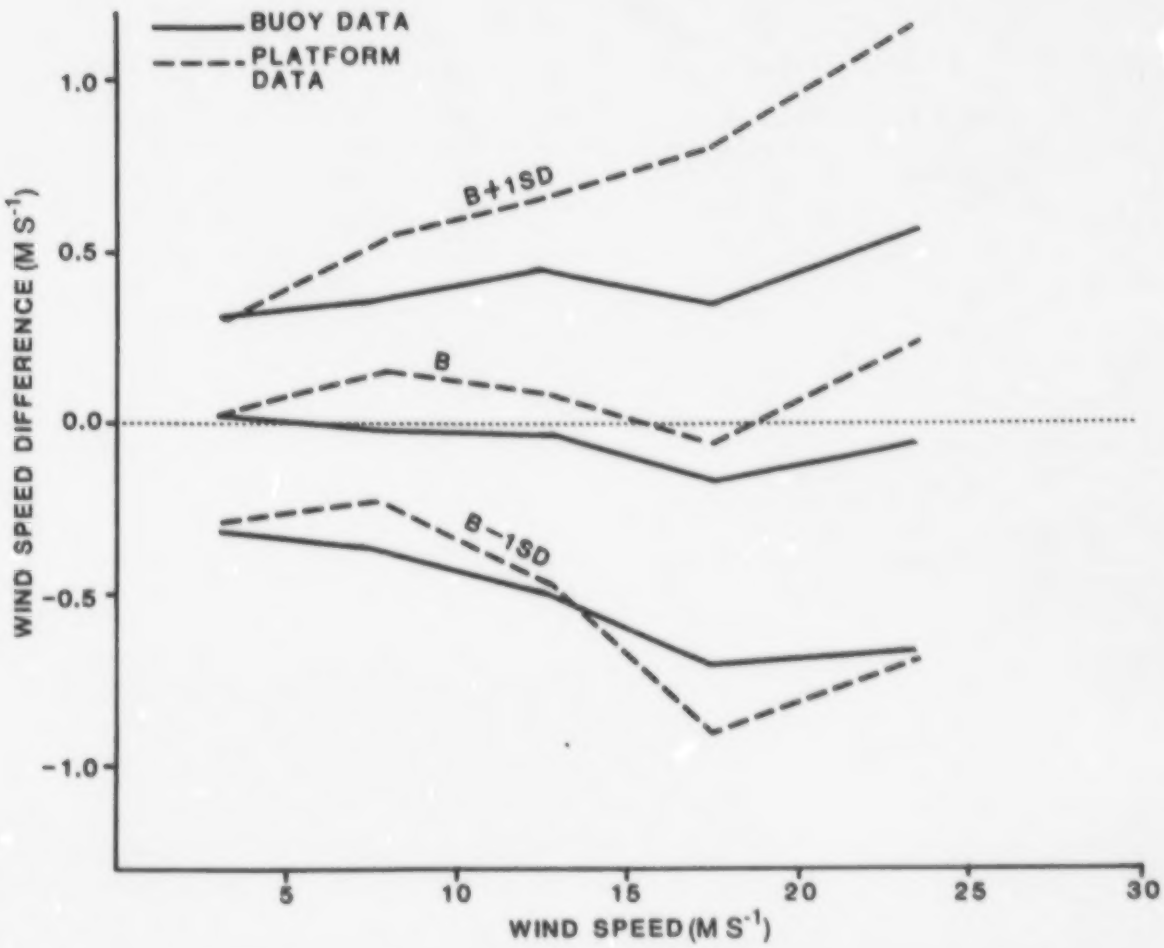

Figure 1. Statistics summarizing the difference in wind speeds between duplicate anemometers. The bias (B) plus and minus one standard deviation (SD) are plotted as a function of wind speed.

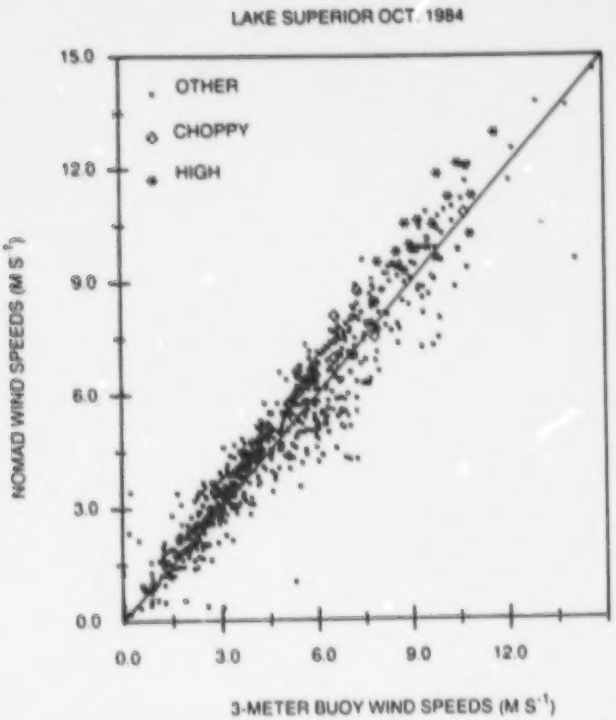

Figure 2. Wind speeds measured by a NOMAD buoy plotted versus speeds measured by an adjacent 3-meter discus buoy. Both speeds were measured by anemometer number 1. Data were stratified by sea state. (See text for details of the stratification.)

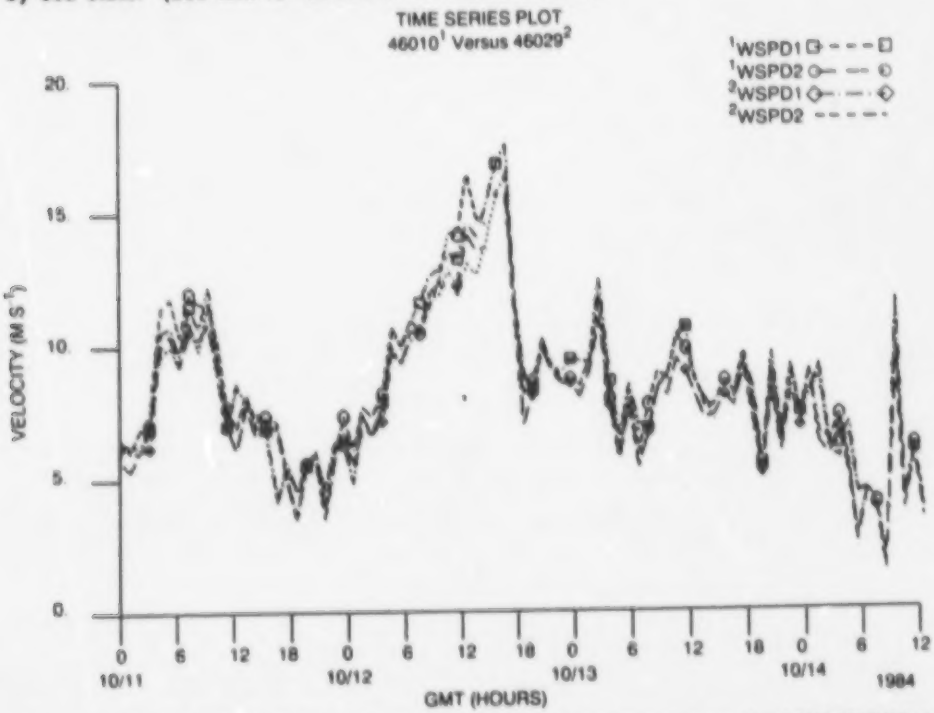

Figure 3. A time-series plot of wind speeds reported by two anemometers on the LNB (46010) and by two anemometers on the 3-meter discus buoy (46029). In the legend, the top two line types identify the LNB winds.

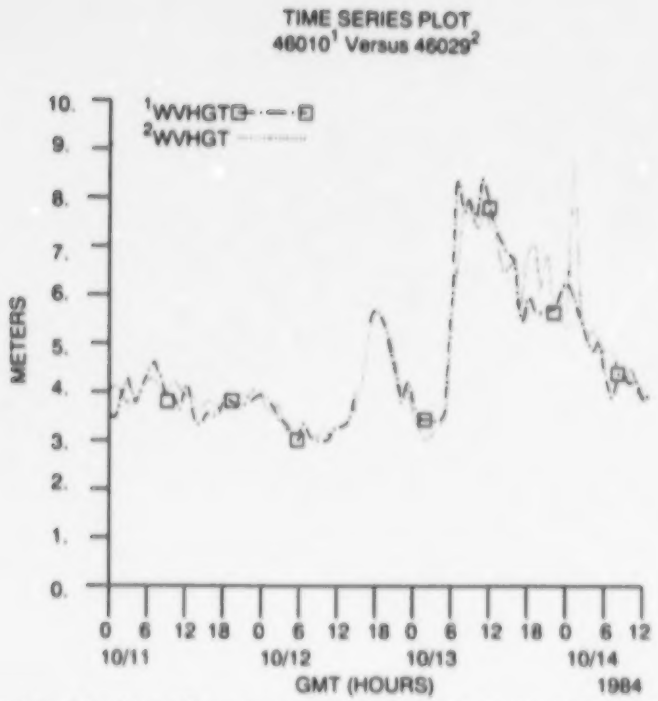

Figure 4. A time-series plot of significant wave height reported by the LNB (46010) and the 3-meter discus buoy (46029).

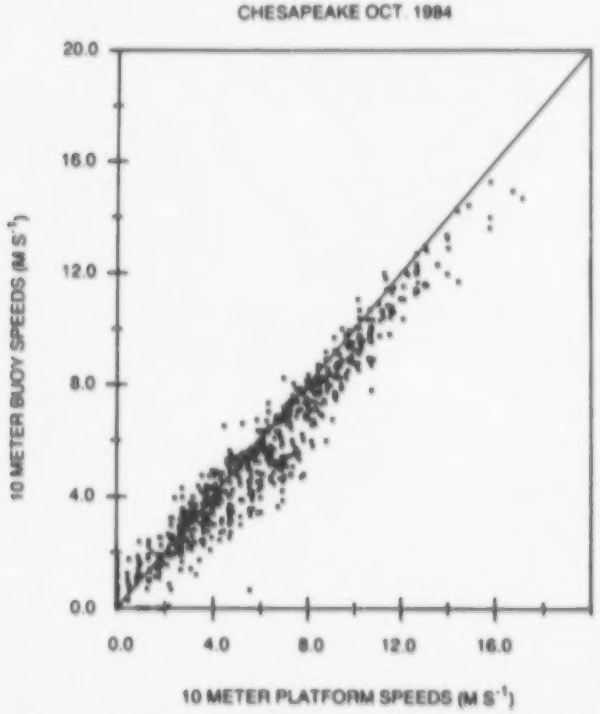

Figure 5. Wind speeds from a 3-meter discus buoy are compared to speeds measured by anemometer number 1 on an adjacent platform. Both speeds were adjusted to a 10-meter height before plotting.

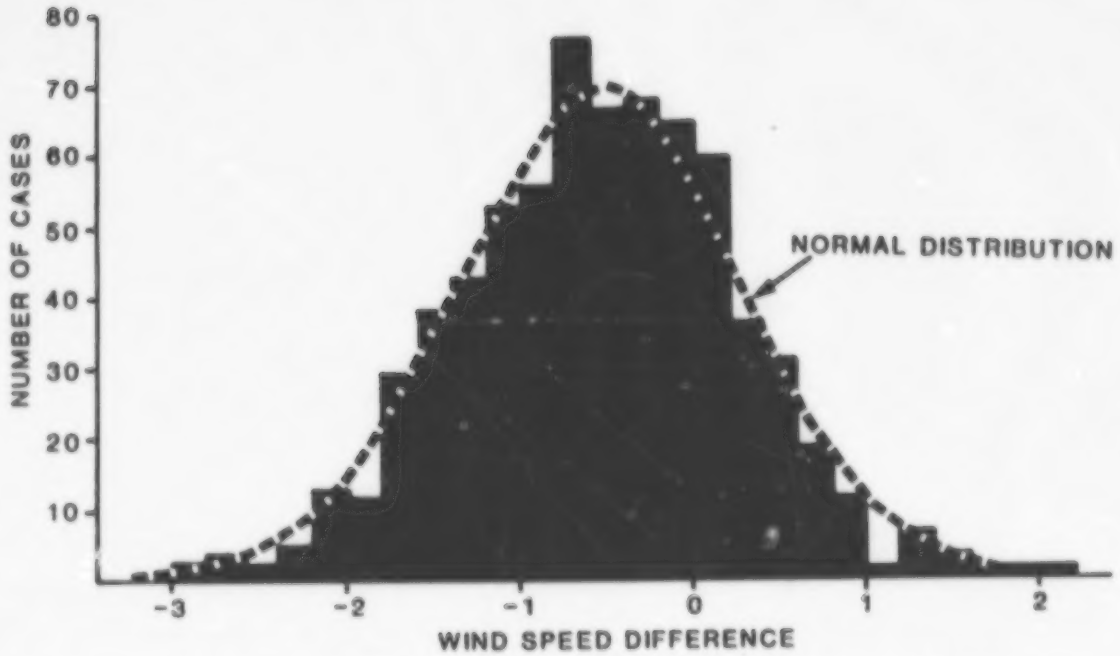

Figure 6. The frequency distribution of the buoy wind speeds minus the platform wind speeds.

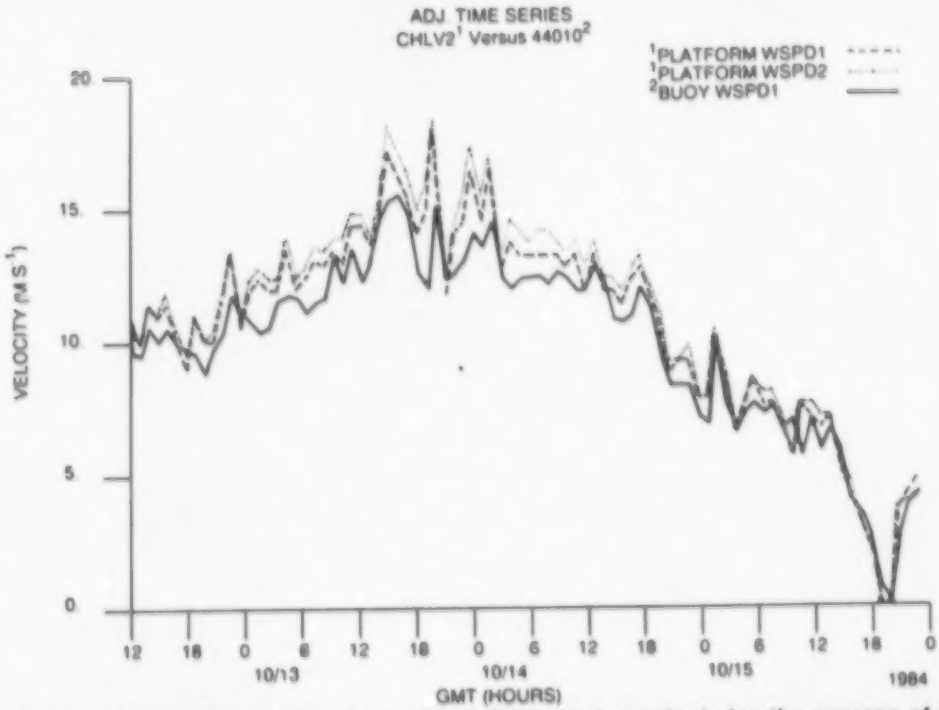

Figure 7. Time series of platform and 3-meter discus buoy wind speeds during the passage of Hurricane Josephine. Both speeds were adjusted to a 10-meter height.

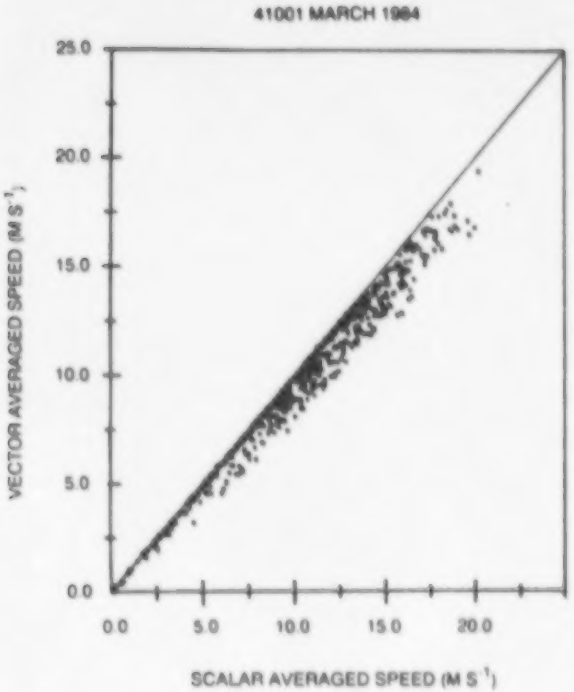

Figure 8. A comparison of scalar and vector averaging techniques for wind speed.

SURFACE ANALYSIS OVER THE OCEANS - SEARCHING FOR GROUND TRUTH

By

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ABSTRACT

For the Atlantic storms in ERICA IOP 1-5, NMC surface analyses are compared with two sets of research analyses prepared later. The positions of cyclone centers agree within 100 km on average only between the two research sets. RMS deviations of the automated analysis positions from the research positions are 180 km. Central pressures are not deep enough, especially in the automated analyses. Comparison of reported pressures with the research analyses shows that those from the moored buoys and C-MAN stations were most accurate and reliable. The drifting buoys were nearly as good, as were the best ships.

RESUME

Pour les tempêtes atlantiques du projet ERICA IOP 1-5, nous avons comparer les analyses de surface du NMC avec deux séries d'analyses faites par la suite dans le cadre de recherches. Les positions des centres dépressionnaires se retrouvent en dedans de 100 km en moyenne en ce qui concerne les analyses de recherche. Les écarts quadratiques moyennes des positions des analyses automatisées par rapport aux positions des analyses de recherche sont de 180 km. Les pressions centrales ne sont pas assez profondes, surtout sur les analyses automatisées. En comparant les pressions rapportées et les analyses de recherche, nous constatons que les données provennat des bouées fixes et des stations C-MAN sont les plus précises et fiables; les bouées dérivantes et les meilleurs navires étant presqu'aussi bons.

INTRODUCTION

Analysis over oceanic regions is much more difficult and uncertain than analysis over land, because of the paucity and irregularity of observations, and because of their varying reliability. For the first five Intensive Observational Periods (IOP's) of the ERICA field phase over the western North Atlantic December 1988-February 1989, various surface analyses were examined. These included the automated initial analyses in the Medium-Range Forecast (MRF) runs of NMC's global spectral model and Nested Grid Model (NGM), operational manual analyses prepared at NMC, for North America and adjacent oceanic sectors transmitted at 40 minutes after the nominal time of observations (NA), and for the Northern Hemisphere transmitted at 1 h 40 minutes after observation time (NH). In addition, two sets of

research analyses, manually prepared after the fact, were considered. These were done by Professor Greg Forbes, ERICA forecast coordinator (GF), and by the present author (FS). All manual analyses used satellite imagery, in addition to all available *in situ* observations.

The research analyses are considered to be the closest approximation to what was actually happening out there, because of the use of a number of observations received too late for operational analysis (including those from ships, drifting buoys, and low-level aircraft flights), because of the possibility of establishing continuity both before and after a given time, and because of the relief from haste imposed by operational deadlines. The FS analyses were arbitrarily taken as ground truth, owing to a slightly larger data base and slightly later preparation time.

DATA AND RESULTS

For the period of study, 46 FS analyses of cyclones could be compared with one or more of the others. The comparison is exclusively in terms of the analyzed positions and central pressures of low centers. The FS maps were at intervals of 6 h, except for two instances of 3-h during rapid intensification in IOP's 2 and 4. The GF and NA maps were at 3-h intervals, while the NH maps were at 6-h intervals. The NGM analyses were at 0000 and 1200 UTC, and the MRF analyses were available only at 0000 UTC. The results of the comparisons of the various analyses with the FS maps is summarized in Table 1.

Table 1

Mean latitude and longitude (degrees)
and mean central pressure (mb) for the FS maps.
Mean geographic bearing (degrees)
and distance (km) from this position,
and mean central pressure deviation(mb)
for the other map series.
Values in parentheses are RMS deviations from the means.

FS analyses: 37.6N (4.7) 65.7W (7.1) 987 (20) N = 46

Series	Bearing/distance	Pressure	N
GF	272/31 (69)	+0.5 (2.5)	35
NH	066/11 (107)	+0.6 (4.0)	29
NA	063/08 (131)	+2.1 (5.6)	34
NGM	152/34 (181)	+3.4 (3.5)	17
MRF	217/45 (179)	+7.5 (5.7)	8

The 3 sets of manual analyses agreed with the FS analyses more closely than did the automated analyses, with respect to both position and central pressure. The positive pressure deviations for all series suggest an FS bias toward deep lows, which we acknowledge but hope is subliminal. Only the GF analyses showed an RMS position deviation smaller than 100 km. Lack of numerous observations from ships during the first 40 minutes after observation time produced somewhat larger position and pressure deviations for the NA series than for the other manual ones. Larger mean and RMS position deviations for the NGM and MRF analyses attest to the difficulty of automated dealing with ships' observations, with their rich and creative variety of errors. The sample of comparisons for the MRF is extremely small, but the substantial SWward position bias and insufficient pressure depth was found also in a study of a larger sample of cyclones over the western Atlantic. The lack of depth of central pressure may reflect coarser resolution in this analysis model than in the NGM.

These results confirm that verification of model predictions of the central pressure of cyclones against initial analyses produced by the models themselves may fail to show a systematic underestimate of deepening seen when verification is with respect to the manual analyses performed with the benefit of ships' observations. Extreme cases show discrepancies near 20 mb, in spectacular events which would not be known to have occurred at all were the automated analyses to be considered as ground truth. The IOP 4 cyclone was such a case.

The most difficult analyses were probably those for IOP 2, to judge from the number of large discrepancies in the various analysis series (despite the abundance of data), and from the complexity of the cyclone development. This is illustrated in Fig.1, just prior to the onset of maximum intensification. The southernmost cyclone, itself a product of a complex development north of the Bahamas, had been in existence for more than 24 h and had deepened substantially if not spectacularly. It was about to lose its identity owing to development to the NW. A new low had appeared off the Virginia Capes, and in the GF analyses underwent explosive deepening. In the FS analyses, however, the ultimate development originated as a barely visible third center between the other two. We will not attempt here to resolve this difference of interpretations.

In any case, a single center dominated the growing circulation 12 h later, as shown in Fig.2. Even at this time, however, the GF analysis showed the center about 115 km farther NW with a central pressure 4 mb higher. In the NH analysis the position was closer but the central pressure was 10 mb higher.

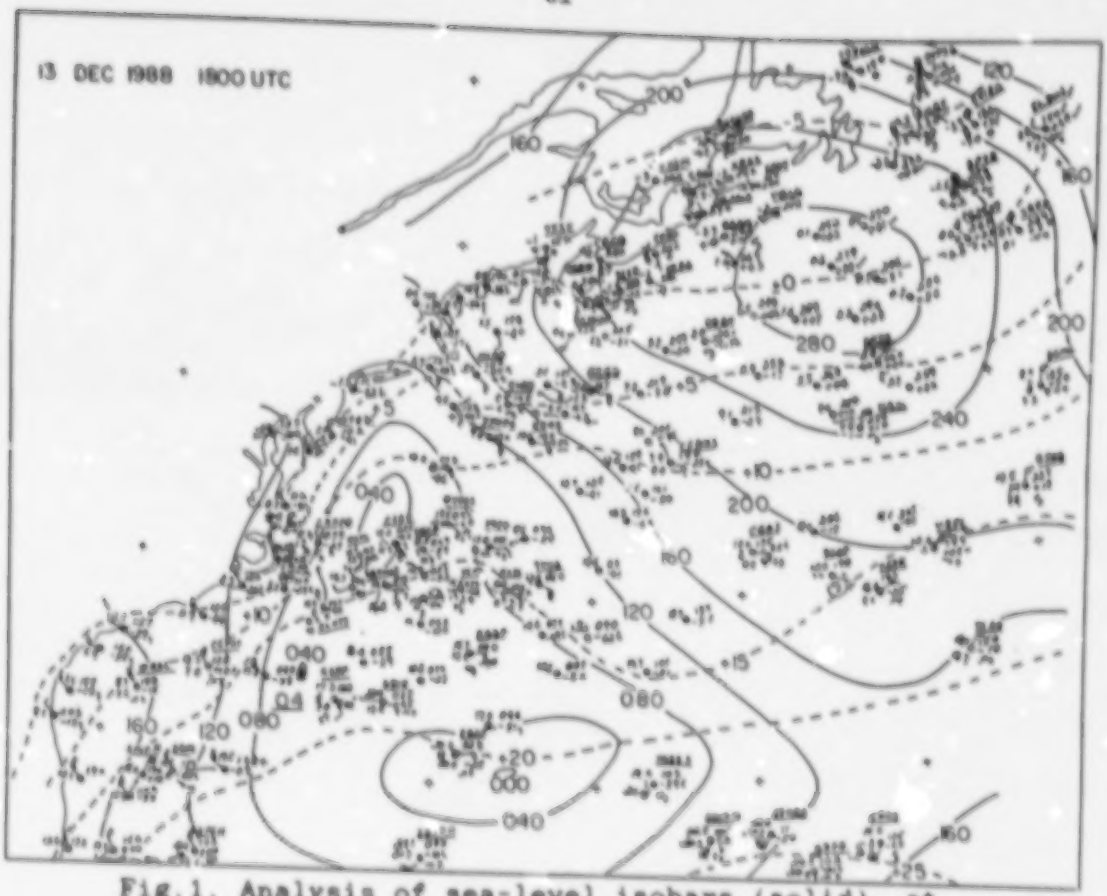

Fig.1. Analysis of sea-level isobars (solid), at intervals of 4 mb and of surface isotherms (dashed) at 5-C intervals, at beginning of rapid deepening in IOP 2. Observations are plotted with the conventional model. Those showing only temperature, pressure and tendency are from drifting buoys.

A by-product of the research analyses is careful documentation of the discrepancy between observed pressure values minus those indicated by the FS analysis at the point of observation. These are taken to be errors in the observations. Comparisons were made for 448 platforms, each providing between 1 and 38 observations during the period of comparison. Of the 279 platforms contributing at least 3 observations, 161 (58%) produced pressure data at all times that could be fitted by the analysis with a discrepancy of no more than 1 mb. Of the remaining 169 platforms, 70% were in equally close agreement, reflecting no doubt the reduced opportunity for getting it wrong.

For each of the 279 platforms reporting at least 3 times, mean and RMS errors were calculated. Distributions of these quantities appear in Table 2.

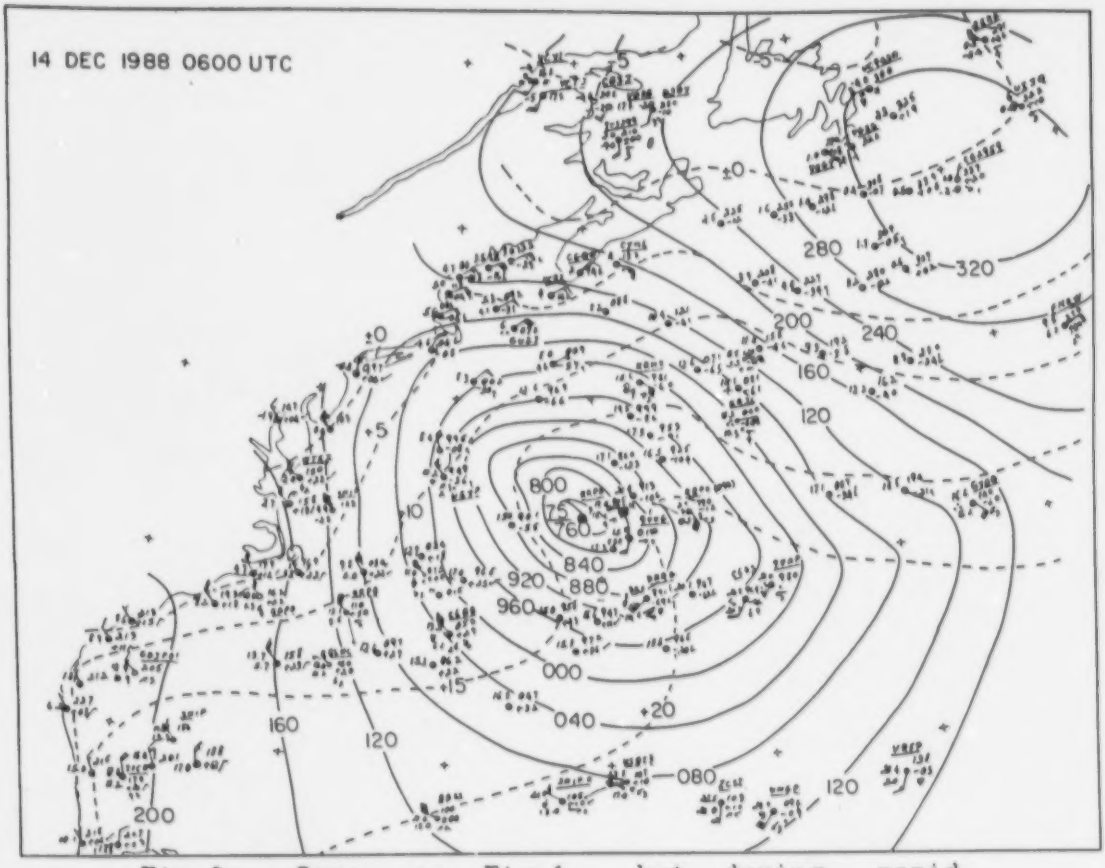

Fig.2. Same as Fig.1, but during rapid deepening.

Table 2

Mean and RMS pressure errors (halves of mb) for platforms providing at least 3 observations

	≥+8	+8	+7	+6	+5	+4	+3	+2	+1	0	-1	-2	-3	-4	-5	-6	-7	-8	≤-8
Mean	1	1	3	3	3	4	7	17	42	113	31	23	14	7	1	4	1	1	2
RMS	3	5	3	6	5	8	16	55	130	48									

These data were stratified according to platform type. The special drifting buoys were considered apart from the regular moored buoys and the C-MAN platforms along the US coast, and the ships were stratified according to the first letter or number of the radio call-sign. Results appear in Table 3. The moored buoys C-MAN stations appeared to be most reliable, with the drifting buoys somewhat less so.

The group of most reliable ships was about on a par with the drifting buoys, perhaps as a matter of chance since the individual samples were small. Among ship categories with a respectable sample size, those with call-signs beginning with G or C fared best, along with those for which none was provided.

Table 3

Mean and RMS pressure discrepancies between reported and FS-analyzed pressures

Source Category	N	% of platforms mean error ≥+1 mb	% of platforms RMS error ≥1 mb
C-Man and moored buoys	30	0	0
Drifting buoys	55	4	11
ABDJST234-ships	31	10	6
G-ships	13	15	15
Unidentified ships	16	25	6
C-ships	30	13	20
W-ships	16	19	25
U-ships	10	40	20
V-ships	28	32	29
K-ships	13	38	13
EFILNOPZ9-ships	37	40	30

indicating that this oversight did not imply a poor observation. The W- and K- ships did not do as well as we might have hoped (to say nothing of the N-ships!), while the U-ships, which the folk lore holds in poor repute, did not do especially badly. Any conclusions must be be tentative, owing to the generally small sample size. Errors in a given ship's observations were reasonably consistent in time, but example of wild values, due to careless observation or communication error, could be found in any category.

An opportunity to test the FS analyses on independent data arose when a group of 45 late observations for IOP 4 and 5 was recently received from the ERICA Data Center. Of these, 15 had in fact been received through other channels and had been used in the analysis. Of the remaining 30, 21 fitted the analyses with a discrepancy of no more than ± 1 mb, with 2 extreme values of +4 mb and 1 of -4 mb. One of the ships (NHNF) appeared to have a low bias of 2 or 3 mb, and an extreme +4 mb was almost certainly an erroneous value from XCBR. With the rest, however, the discrepancies reflected errors in the reported pressure or in the analyses. The large values not obviously in error were in regions of strong gradient. Generally, the reliability of the FS maps, in terms of RMS analysis error, is probably not more than ± 1 mb.

We hope that this information is helpful to those who wish to undertake oceanic surface analysis or who wish to use the existing maps. We urge that features of these analyses be referred to as "analyzed" rather than "observed". Use of the latter tends to conceal the uncertainty inherent in this challenging and fascinating enterprise.

SATELLITE SENSOR MICROWAVE IMAGER (SSM/I) VERIFICATION STUDY (1989/1990)

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ABSTRACT

SSM/I wind speed and rainfall rate were verified mostly in an objective manner by comparison to over 800 interpolated ship and buoy reports. For the most part, SSM/I wind speed estimates were reasonable. When precipitation was present or detected, the agreement between SSM/I and actual wind speeds was reduced. Light winds were underestimated and winds greater than 30 knots were overestimated. SSM/I was poor in detecting precipitation and had a rather high false alarm ratio. When precipitation was detected, rates were found to be reasonable.

La vérification de la vitesse du vent et du taux de précipitation par le SSM/I a été effectuée objectivement en comparant l'information détectée avec les données résultant de l'interpolation de 800 rapports de bateaux et de bouees. Dans la plupart des cas, il semble que l'estimation des vents soit raisonable quoique lorsqu'il y a présence de précipitation où que cette dernière soit détectée, les resultats sont beaucoup moins concluent. Les vents leger sont sous-estimé tandis que les vents supérieur a 30 noeuds sont sur-estimé. La détection de précipitation est assez faible et le rapport de fausse alarme assez eleve. Lorsque la précipitation est detectée, le taux percu est alors justifié.

INTRODUCTION

The Special Sensor Microvave/Imager on board a polar orbiting United States Defence Meteorological Satellite receives passive microwave data and is able to transform the signal into various output such as estimated surface wind speed and precipitation rate. This is done by an algorithm initially prepared by Ph.D Associates and developed by Irene Rubenstein (Ramseier et al).

This output is received by the Canadian Meteorological Centre daily and then distributed to other weather centres in Canada in the form of estimated wind speed (m/s) and precipitation rate (mm/hr) and can be seen in Figure 1.a. In this study, an extensive objective verification of the Satellite output was conducted. The SSM/I output was compared directly to over 800 ships and buoys.

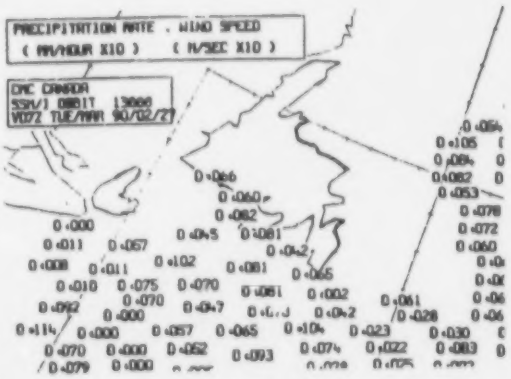


Figure 1.a

DATA ANALYSIS

Reports of wind and precipitation from ships and buoys were collected from surface charts analyzed at regular synoptic hours and were interpolated in time to make their valid time identical with the SSM/I charts. Ship winds speeds had an uncertainty of 3 knots since reports were rounded off to the nearest 5 knots and SSM/I wind speed had an associated uncertainty of 4 knots or 2m/s (Ramseier et al). Reported wind speed were interpolated rather than SSM/I output since it had a lower uncertainty associated and this would keep future uncertainties at a minimum as a result of calculations. The time interpolated ship wind speeds then would have an uncertainty of 6 knots.

Ship positions were interpolated in time and located on the SSM/I charts which had a spatial resolution of 25 km corresponding to about 1/4 of a degree of latitude. If the interpolated ship position was within 25 km of a datum point, then the SSM/I output at that point was used directly. Otherwise the output was interpolated spatially which produced a final uncertainty in the SSM/I wind speed of 8 knots. As a result, when calculated wind speeds were compared to SSM/I winds a total uncertainty of 14 knots was allowed for. This was the maximum absolute uncertainty. Another technique was employed to give a probable uncertainty of 8 knots (Beers).

When reported weather was tabulated, any precipitation that occurred in the past hour or was reported in the distance was considered a precipitation event due to

the resolution of the SSM/I output. For the purposes of time interpolation, precipitation was tabulated only if it was reported before and after the SSM/I chart valid time, with two exceptions;

(i) if precipitation was reported within one hour of the output time then interpolation was not carried out, and precipitation was tabulated exactly as reported.

(ii) if it was unsure whether precipitation was occurring at the SSM/I time then SSM/I was given the benefit of the doubt.

The same method was applied in tabulating interpolated sky condition and visibility. If visibility changed from poor (less than 5/8 mile) to good (greater than 6 miles), then weather was tabulated as 'mist'. Due to a lack of space the tabulated values are not listed here.

WIND SPEED COMPARISONS

In view of the uncertainty associated with the interpolated wind speeds, any comparisons within 14 knots (maximum error) and 8 knots (probable error) were considered as agreements.

Total Cases Examined = 939
No. with difference <14 knots = 759 (81%)
No. with difference <8 knots = 488 (52%)
Mean wind difference=3.2 knots
Standard Deviation=10.7 knots

When considering absolute error, SSM/I wind speeds were reasonable for a good majority of the time. For buoys, the agreement was about 88 percent. When considering probable error 8 knots, the percent agreement was noticeably reduced. By focusing on the cases where agreements did not occur more insight was obtained as to where improvements were necessary. Examining cases where SSM/I detected precipitation revealed the following.

Total Cases (SSM/I Precipitation) = 54
No. with difference <14 knots = 22 (41%)
No. with difference <8 knots = 17 (32%)

This illustrates that when SSM/I detects precipitation, the percentage of wind speed agreements is significantly reduced. This conclusion agrees with previous studies (Ramseier et al, McIldoon).

SSM/I output supposedly represents wind speeds at the sea surface whereas ship winds are usually measured at 10-20 metres. Due to frictional effects at the surface, we would expect ship wind speeds to be larger. The cases where SSM/I winds exceeded actual winds by maximum and probable errors were tabulated as follows;

Cases (SSM/I wind-Actual>14 knots) = 58
No. with SSM/I precipitation = 32
(59% of cases with SSM/I precipitation)

Cases (SSM/I wind-Actual>8 knots) = 82
No. with SSM/I precipitation = 33
(61% of cases with SSM/I precipitation)

Whether the probable error or maximum error is used the result is the same. Most of the time that SSM/I detected precipitation, SSM/I winds were unexpectedly higher than actual winds.

An analysis of the differences between actual and SSM/I winds was made as a function of the SSM/I wind speed. The results are listed below in Table 1.

Table 1

SSM/I Wind Speed	Actual Wind Speed minus SSM/I Wind Speed (knots) 0 to 15	16 to 25	>26	(-1 to -10)	(-11 to -21)	<-21
0-9	280	36	4	10	-	-
10-19	301	31	8	65	2	-
20-29	123	12	-	79	16	1
30-39	21	4	3	34	30	8
>40	2	-	-	5	15	21

From Table 1, the percentage of the time that actual winds were larger is;
96% for SSM/I wind speed < 10 knots
72% for SSM/I wind speed 10-19 knots
58% for SSM/I wind speed 20-29 knots
29% for SSM/I wind speed 30-39 knots
5% for SSM/I wind speed >40 knots

So it is clear that SSM/I underestimates light winds and overestimates winds 30 knots and above.

A correlation matrix was produced to determine any other obvious relationships among the variables. The result can be seen in Table 2.

For a sample size of about 900, a correlation coefficient of r=.1 is significant at the 1% level. This means that there is only a 1% chance that in reality (an infinite sample size) a correlation may not exist (Spence et al). All of the coefficients in Table 2 are larger than .1 and so are significant.

SSM/I wind speed shows a high positive correlation with SSM/I derived rainfall rate. This is consistent with earlier results. The Wind Difference in Table 2 is Actual Wind Speed minus SSM/I Wind Speed. A significant negative correlation exists between SSM/I Wind Speed and Wind Difference. This simply states the same conclusion from the results of Table 1.

Table 2 - Pearson Correlation Matrix

	Actual Wind Speed	SSM/I Wind Speed	SSM/I Precipitation Rate
Actual Wind Speed	1.000		
SSM/I Wind Speed	.536	1.000	
SSM/I Precipitation Rate	.041	.421	1.000
Wind Difference	.333	-0.619	-0.433

VERIFICATION OF PRECIPITATION

Precipitation verification was carried out in two stages. First the ability of SSM/I to detect precipitation, secondly its ability to detecting precipitation rate. SSM/I precipitation rate values were interpolated subjectively. A zero value was given only if the ship position was surrounded by zero values.

Precipitation Detection

Cases where precipitation occurred = 225
Cases (precipitation detected) = 26 (10%)

Obviously precipitation was not detected very well. If we examined cases with rain drizzle and snow separately, we found the following.

No. of cases with rain = 152
No. of cases detected = 20 (12%)

No. of cases with drizzle = 16
No. of cases detected = 4 (25%)

No. of cases with snow = 63
No. of cases detected = 1 (2%)

The ability to detect snow was a very poor 2 percent.

Upon examining only cases where SSM/I detected precipitation, the following results emerged.

No. of cases = 44
No. of correct detections = 26
No. of false detections = 18

So SSM/I gives a false alarm 40 percent of the time. Upon examining further details where false detections occurred it was found that in all cases, sky conditions were either broken or overcast or fog or mist was present. This means that in all cases, the signal reaching the satellite had to pass through a layer of significant liquid water content.

Verifying Precipitation Rate

Surface weather reports from ships do not include precipitation rate so the only method of verifying would be according to the categories of light, moderate, and heavy rain.
According to The Manual of Surface Weather Observations, light rain has a precipitation rate less than 2.5 mm/hr. The rate for moderate rain ranges from 2.6 to 7.5 mm/hr and for heavy rain it is greater than 7.5 mm/hr. Since the SSM/I precipitation rate has an uncertainty of 5 mm/hr it cannot distinguish very well between light and moderate rain. Any values of SSM/I output between zero and 7.5 mm/hr were considered to be an agreement when verifying light rain.

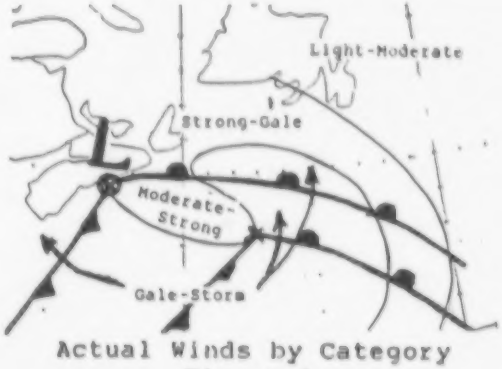
Cases with light rain detected = 19
Cases (appropriate rainfall rate) = 19

It seems that when the Satellite does detect light rain it always gives an appropriate rainfall rate.

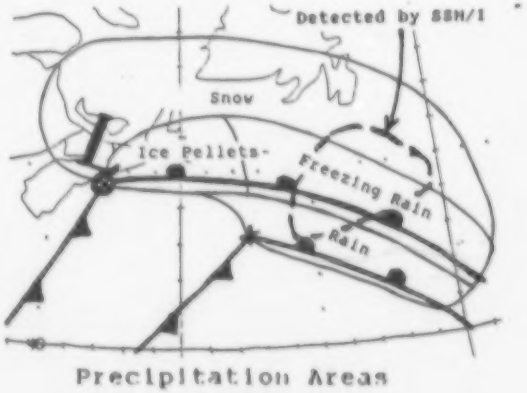
Any values of Satellite detected rainfall rate between zero and 12.5 mm/hr were considered an agreement when verifying moderate rain. Moderate rain was detected in only one case and the Satellite gave a reasonable rainfall rate. Heavy rain was detected in only one case but SSM/I did not give an appropriate rainfall rate.

A SYNOPTIC LOOK

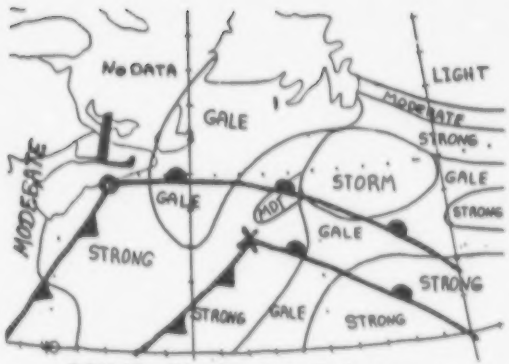
A comparison was conducted for a particular storm that occurred on January 30, 1990. Two 21z surface analyses were compared with an SSM/I chart valid at that same time. The first analysis represents wind speed by category (fig. 1). It was constructed by analyzing pressure gradients at 18z and 00z and using land stations then time interpolating subjectively. This was done by relating wind speed areas to synoptic features. The second analysis was constructed in a similar manner with the added use of satellite photos and represents areas of precipitation (fig. 2). The SSM/I chart



Actual Winds by Category
Figure 1



Precipitation Areas
Figure 2



SSM/I Winds by Category
Figure 3

was contoured according to wind speed into the same categories (fig. 3). Detected precipitation from the SSM/I chart was superimposed on fig. 2 as a dashed line.

Comparing figures 1 and 3, we see that there is reasonable agreement. One significant difference is that SSM/I wind speed behind the cold front is significantly lower than expected wind. Other cases revealed similar results. The area of detected precipitation on figure 2 corresponds fairly well with an area of storm force winds on figure 3. This further reveals the positive correlation between SSM/I wind speed and detected precipitation.

In figure 2 we compared actual and SSM/I precipitation. A good portion of the liquid precipitation was detected by the satellite but most of the solid precipitation went undetected. This is consistent with the objective findings.

In earlier studies (Ramseier et al.), it was suggested that SSM/I output might be useful in identifying synoptic features when analyzing surface charts in real time. Figure 3 suggests that the position of the analyzed frontal wave nearly coincides with a small minimum in the satellite estimated wind speed. The location of the wave perhaps could have been adjusted to fit this minimum.

SUMMARY AND CONCLUSIONS

Considering absolute uncertainties for a good majority of the time (81%), SSM/I wind speed values were reasonably good. However, when the Satellite detected precipitation the percentage of wind speed agreement was significantly reduced. There were a number of times where the SSM/I wind speed exceeded the actual wind speed by a significant margin. This was an unexpected condition and in most of these cases the satellite detected precipitation. This was consistent with the significant positive correlation between SSM/I Wind Speed and Precipitation Rate. The satellite underestimated light winds and overestimated winds 30 knots and greater. This effect was also described by the significant negative correlation between SSM/I wind speed and the difference of SSM/I wind speed from actual wind. It seems that the satellite may underestimate wind speeds behind cold fronts. It may be useful for fine tuning the position of lows and waves in real time analysis.

In detecting precipitation, the satellite did not do very well. When rain occurred, it was detected only 12 percent of the time, when drizzle occurred, the detection was only 25 percent, and when snow occurred the detection was 2 percent of the time. In cases where SSM/I did detect precipitation, it illustrated a rather high false alarm rate of 40 percent. In all of the false detection cases, a layer of high liquid water content was present in one form or another and may have been responsible for the incorrect detections. Due to the uncertainty in its estimate of precipitation rate, SSM/I could not distinguish very well between light and moderate precipitation. However, when the satellite did detect precipitation it almost always gave appropriate rates.

The algorithm for detecting precipitation obviously needs to be improved in order for SSM/I output to be used in aiding with surface analyses. As well, there still exists too much coupling between wind speed estimates and detected rainfall which in turn affects the accuracy of wind speed estimate.

These are preliminary findings and more will follow in a Regional Technical Note to be published later this spring.

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ICE BRANCH DEPLOYMENT AND OPERATIONAL USE OF DRIFTING BUOYS AND ICE BEACONS

By

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T. Chen
Ice Centre Environment Canada

ABSTRACT

Ice beacons are deployed by Ice Branch, Environment Canada, on ice floes in ice covered waters. Also in a cooperative effort with the International Ice Patrol, drifting buoys are deployed in iceberg infested waters. Positional information from these sources, together with information from beacons and buoys deployed by other agencies, is used operationally by Ice Branch. Ice information is updated with respect to wind and current induced ice drift, ice drift models are evaluated, and better current input to drift models is produced. This poster session describes the various applications of ice beacons and drifting buoys.

RESUME

La Direction des glaces d'Environnement Canada s'occupe d'installer des balises sur les floes qu'on retrouve sur les eaux recouvertes de glaces. De plus, en collaboration avec la Patrouille internationale des glaces, des bouées dérivantes sont installées sur les eaux envahies d'icebergs. La Direction des glaces se sert, de façon opérationnelle, des renseignements provenant de ces sources, de même que ceux qui sont fournis par les balises et les bouées d'autres organismes. Les renseignements sur les conditions glacielles sont mis à jour en fonction des vents et de la dérive provoquée des glaces, les modèles de dérive sont évaluées, et le rôle du courant sur les modèles de dérive est ainsi réhaussé. Cette réunion informelle fait état des diverses utilisations des balises et des bouées dérivantes.

INTRODUCTION

For the most part, meteorologists use buoys and ice beacons to provide environmental information in data sparse areas, especially over the oceans. The air pressure, air temperature, sea surface temperature and wind measuring devices have a direct impact on the accuracy of meteorological and oceanographic predictions. To meteorologists, drift of the sensor packages is a major problem.

On the other hand, Ice Branch is tasked to provide advice on the growth, movement and decay of sea ice and icebergs. Drift of the platforms gives an accurate account of ice motion due to winds and current.

ICE BEACONS

Large areas of the arctic such as Baffin Bay become totally ice covered during late fall and quite often don't completely clear the following summer. The ice remains mobile throughout the year, being driven by meteorological and oceanographic forces. Shipping activity into the Northwest Passage must pass through Baffin Bay. Therefore Ice Branch attempts to produce a daily ice analysis for the area during the June to November season. During the remainder of the year, composite ice charts are produced at monthly intervals. Due to the circulation of the area, thick

floes of ice drift southward. These continuously thickening floes may threaten shipping activity off the Labrador coast a few months later. Additionally, large floes of ice which have survived several summers of melt often drift from the Arctic Ocean between Greenland and Ellesmere Island into northern Baffin Bay. These very thick multi-year ice floes can create havoc in the approaches to Lancaster Sound and may eventually reach Newfoundland. Aerial reconnaissance of the area is an expensive proposition and satellite imagery of the ice is infrequent due to long periods of darkness and cloud cover.

Ice Branch has identified the need for low cost, air deployed ice beacons to be used for tracking movement of ice floes. Under contract, METOCEAN has designed and developed a Compact Air Launched Ice Beacon (CALIB). These beacons may be deployed manually or from aircraft gravity tube launchers and are capable of withstanding the resultant shock of landing. An internal view of the CALIB and its specification are shown in **Figure 1**.

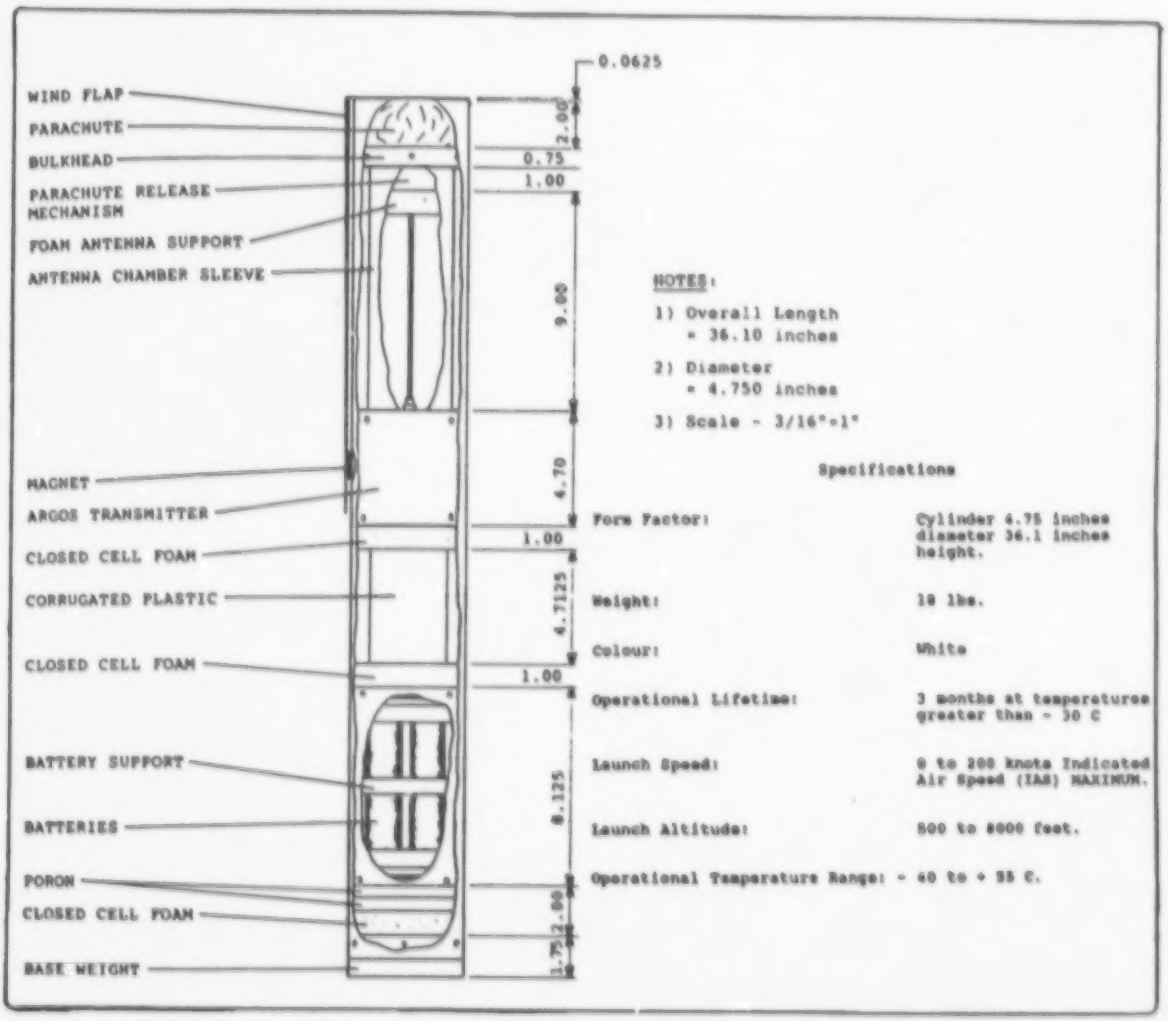

FIGURE 1
View of the Compact Air Launched Ice Beacon and its specification.

Through SERVICE ARGOS reports are received in the DRIBU code via the Global Telecommunications System directly into Ice Centre computer systems. The positions are graphically displayed for incorporation of real time ice drift into daily ice analysis charts and to compare with drift forecasts produced by ice models.

The Baffin Bay water currents are not well documented. Conclusions can be reached by comparing drift tracks of beacons with the strength and direction of the winds estimated from pressure patterns. **Figure 2** gives an overview of the five ice beacons deployed in northern Baffin Bay during 1989. **Figure 3** gives a detailed view of one position per day for one beacon.

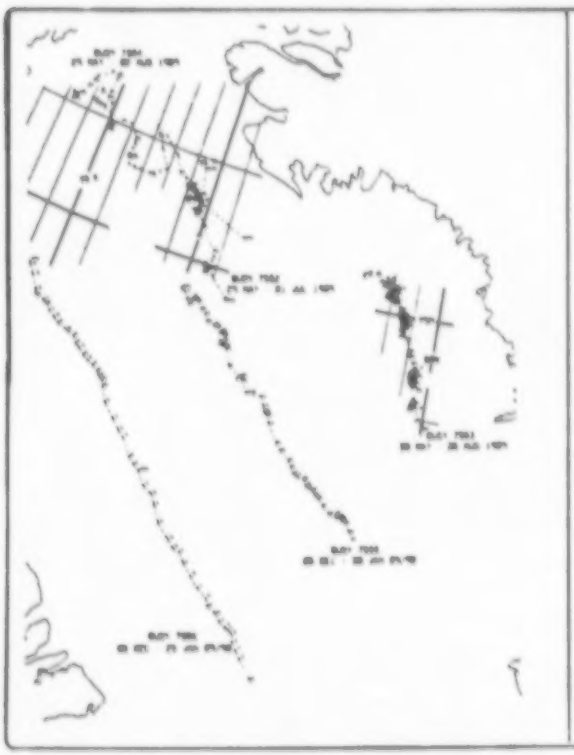

FIGURE 2
Ice Beacon deployed
in northern Baffin Bay
during 1989.

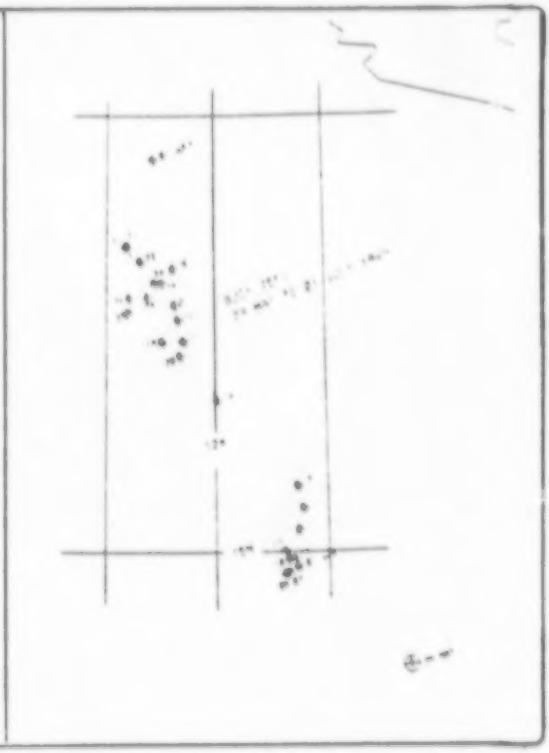

FIGURE 3
Detailed view of
one position per day
for one beacon.

Ice motion in the Arctic Ocean and Beaufort Sea areas is also difficult to monitor using conventional means. Arctic pack ice, consisting of mostly multi-year ice (ice that has survived several summers of melt), normally rotates in a clockwise fashion. The edge of the old pack lies at some distance off the Canadian and Alaska coasts. The area between the coast and pack varies from open water in late summer to thick first year ice for the winter and spring. Drilling operations in the Beaufort and shipping along the Alaska coast into and out of the western arctic can be severely reduced or damage may occur with southward intrusions of old ice. Drifting ice beacons on the pack provide a continuous track of ice motion.

During the summer of 1988, inbound icebreakers and escorted vessels had little difficulty passing through Bering Sea and along the Alaska Coast into the western arctic. However, during the latter part of September the old ice drifted east southeastward to totally block the outbound ships near Point Barrow. Icebreakers suffered damage and two of them had to return to the west coast by the long route through the Northwest Passage and Panama Canal. **Figures 4 and 5** show the tracks of two ice beacons which assisted in the forecasting of that event.

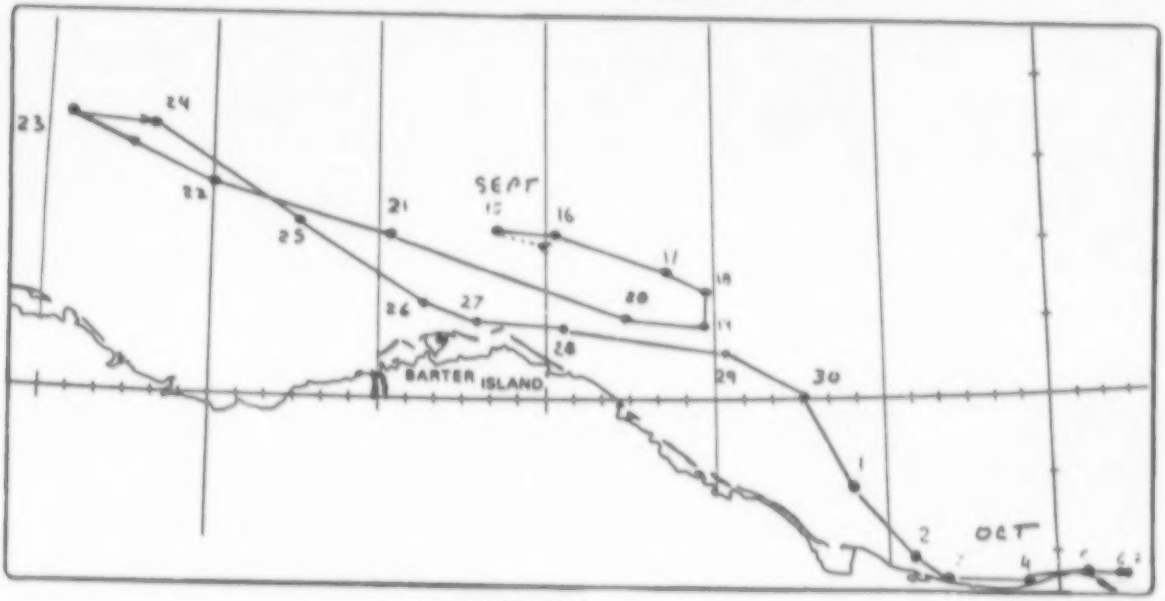

FIGURE 4
Buoy 3831B from Sept. 15 to Oct 13 1988.

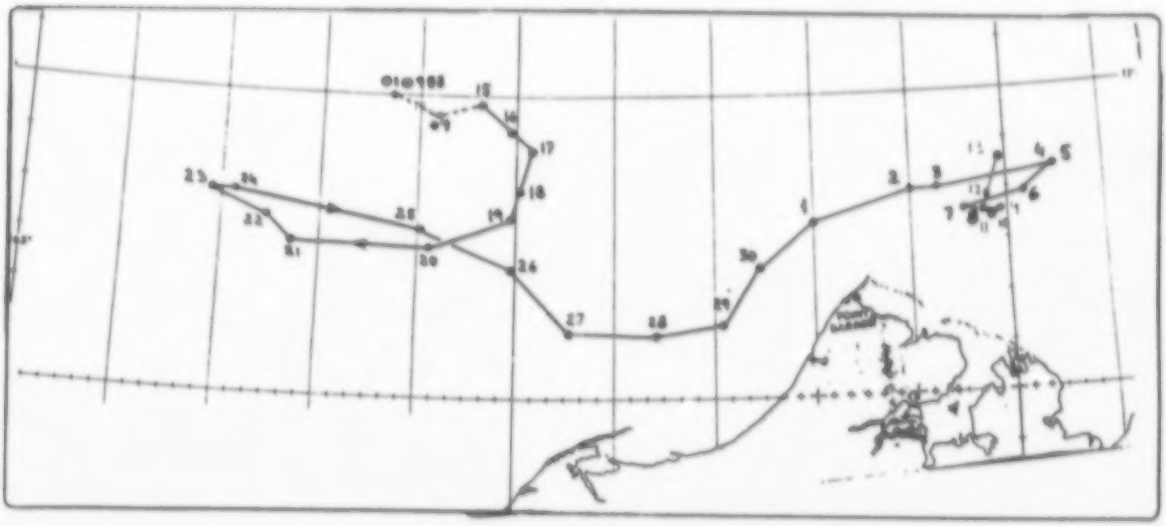

FIGURE 5
Buoy 7054B from Sept. 15 to Oct 07 1988.

Ice Branch of the Atmospheric Environment Service and the International Ice Patrol of the United States Coast Guard are involved in a cooperative effort to monitor the numbers and location of icebergs in Canadian waters and to advise shipping interests on the limit of all known icebergs. Ocean current produce the major force acting on floating icebergs. The International Ice Patrol deploys buoys at selected locations and intervals to provide iceberg drift models with the best possible current input. The buoys are drogued to simulate iceberg drift. In addition to position location they are equipped with sea surface temperature sensors. Through SERVICE ARGOS, the positions are received by and displayed on Ice Centre computers. Graphics editing is used to eliminate tidal fluctuations and spurious positions. One week's worth of positions for each buoy are then input to a current update model. The current update model uses the buoy drift to modify the mean water current which are then used by the iceberg drift model. **Figure 6** shows a section of the mean annual current and **Figure 7** shows a section of buoy track. Only one position per day is shown in order to better outline track.

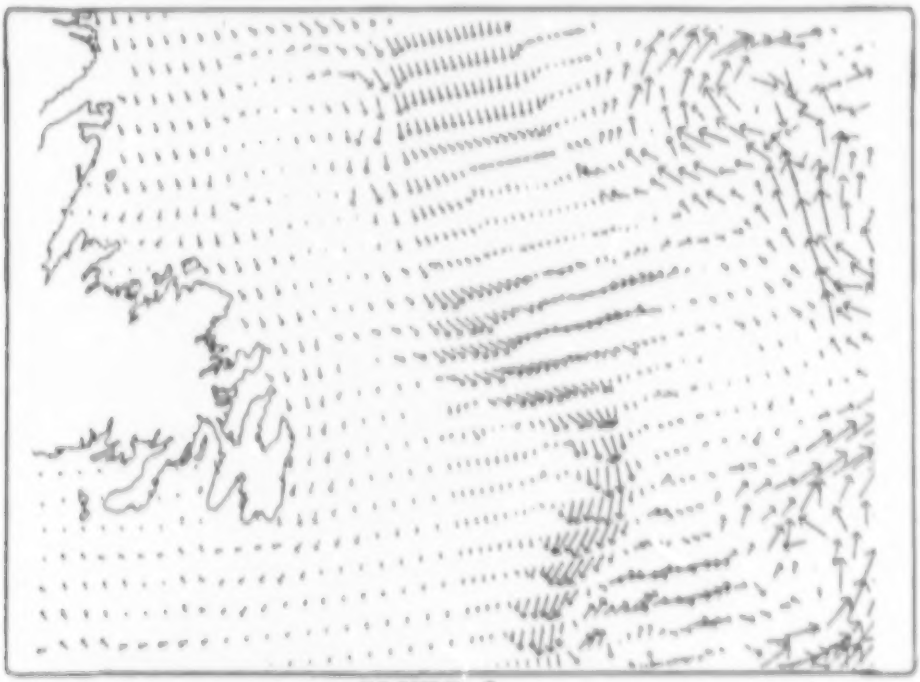

FIGURE 6
Section of the mean annual current.

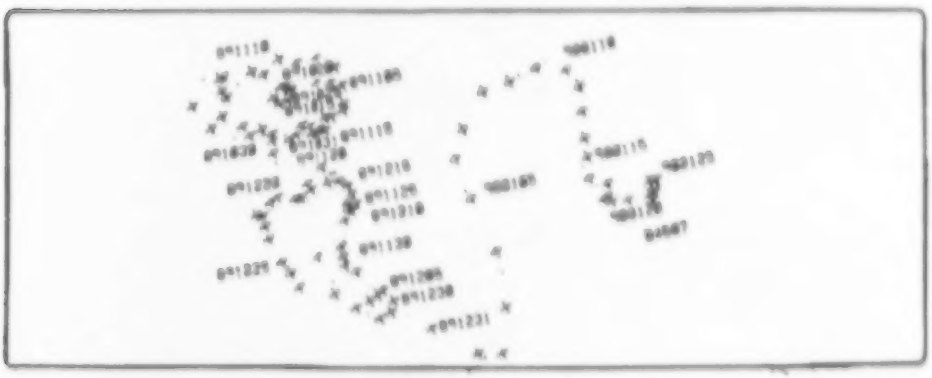

FIGURE 7
Buoy track.

USE OF SATELLITE INFORMATION FOR IMPROVED OCEANIC SURFACE ANALYSIS

Frank J. Smigielski, Meteorological Consultant
and
R. Michael Hoqil, Satellite Applications Laboratory, NOAA/NESDIS

A method for determining minimum surface pressures and pressure patterns of mid latitude oceanic cyclones has been devised. This system is based on a similar method for determining maximum winds in tropical storms. This latter system was developed by Mr. Vernon Dvorak and is in use operationally.

The system for estimating minimum pressures of mid latitude winter season cyclones involves satellite image comparisons at 12 hour intervals. By use of a graphic relationship involving cloud pattern changes, minimum cyclone pressure and associated pressure patterns can be determined.

The poster display will present several cases which demonstrate this relationship.

Nous avons élaboré une méthode pour déterminer la pression de surface minimale et les patrons de pression associés aux dépressions océaniques des latitudes moyennes. Ce système repose sur une méthode similaire qui détermine les vents maximums associés aux tempêtes tropicales. Cette dernière, utilisée opérationnellement, a été développée par M. Vernon Dvorak. La méthode présentée emploie les images satellitaires, prises à 12 heures d'intervalle, qui sont comparées. Par l'entremise d'un graphique les reliant aux changements de patron nuageux, on peut déterminer la pression centrale minimale et les patrons de pressions associés. L'affichage montrera plusieurs cas illustrant cette relation.

INTRODUCTION

One of the challenges facing meteorologists engaged in marine forecasting is determining the minimum central surface pressures of mid latitude oceanic cyclones. This is in part due to a sparse surface reporting network over the oceans, especially at night. Another problem involves the accuracy of the data that is available.

Junker-Haller(1) recognized the need for better oceanic analysis and devised a technique for estimating minimum surface pressures using a single satellite image and cloud pattern recognition as bases to assign central pressures to oceanic storms.

The Experiment on Rapidly Intensifying Cyclones in the Atlantic (ERICA) was an intensive study of rapid developing storms. ERICA combined the talents of a select group of meteorologists, along with the use of specially equipped aircraft, to study the genesis and development of winter storms off the east coast of North America. Combined satellite, aircraft and regular weather data from this experiment is still being studied.

Vernon Dvorak,(2), in the early 1970's devised a system for estimating minimum central pressures and maximum winds associated with tropical cyclones. This method made use of cloud pattern changes over 24 hour intervals. These cloud pattern changes have been shown to be related to changes in tropical storm intensity. This system evolved into a series of eight distinct cloud patterns, six of which are shown as Figure 1.

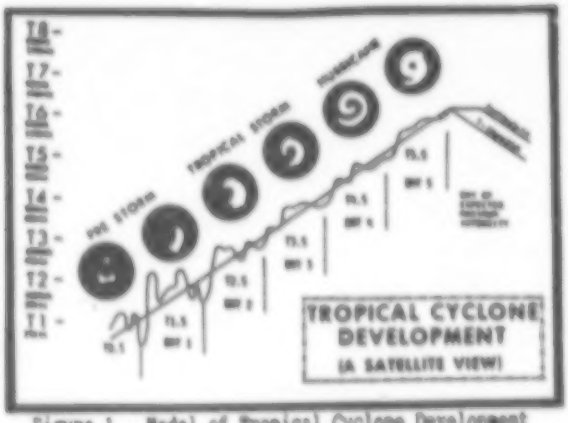

Figure 1. Model of Tropical Cyclone Development and Related Pressures and Maximum Winds

METHODOLOGY

Based on the Dvorak Technique, a step-by-step method was created to determine the minimum central pressure of mid latitude cyclones based on cloud pattern changes. Instead of taking changes over 24 hour periods, a time interval of 12 hours was used. This is because the changes in extratropical systems are more rapid than in tropical ones. Based on 12 hour changes in cloud patterns, a graph of storm evolution showing cloud pattern changes and the relationship to minimum central pressure was developed. (Figure 2) Preliminary results indicate that this system has merit for certain full latitude storms. Other types of storms, such as barotropic and limited latitude were looked at, but the results are only partially complete at this time. The criteria for determining cloud pattern changes is given in Table 1.

TABLE 1: BAROCLINIC DEVELOPMENT INDICATORS
(All Indicators Are Based On 12 Hour Comparisons)

I INITIAL DEVELOPMENT INFRARED IMAGERY	Pressure is above 1005mb
1. Start of "S" shape, or increasing "S" shape 2. Positive vorticity advection area within 10° of baroclinic band (West to northwest of the band) 3. Jet streak approaching band in slight anticyclonic arc (Usually from the westnorthwest) 4. Beginning or increase in cloud brightness within baroclinic band 5. Decrease, or thinning of clouds immediately behind the band	
II CONTINUED DEVELOPMENT INFRARED IMAGERY	Pressure drops to below 1005mb
1. Increasing "S" shape or comma shape 2. Continued increase in bright cloud area in upper portion of "S" 3. Positive vorticity advection area increasing and approaching band 4. Enhanced spiral character to clouds in cold air behind the band	
III END OF DEVELOPMENT INFRARED IMAGERY	Pressure remains steady or rises
1. Comma cloud becomes detached from main band 2. Cloudiness warming and decreasing in comma and band 3. Baroclinic band becoming thin	

PROCEDURE

The procedure used, to develop the curve shown as Figure 2, involved inspecting a series of infrared satellite images at 00GMT and 12GMT for cloud pattern changes prior to storm development.

Using the criteria listed in Table 1, each 12 hour image was compared to the previous one to determine whether cyclogenesis was occurring. If a change in cloud patterns indicated cyclogenesis, then the National Meteorological Center's (NMC) analyzed surface pressure was entered on a graph along with the associated cloud pattern. This was done for the life cycle of the storm. After a series of storms were analyzed, an average curve was developed for each 12 hour segment. The result was a curve relating minimum central pressures and pressure patterns, to cloud patterns as in Figure 2.

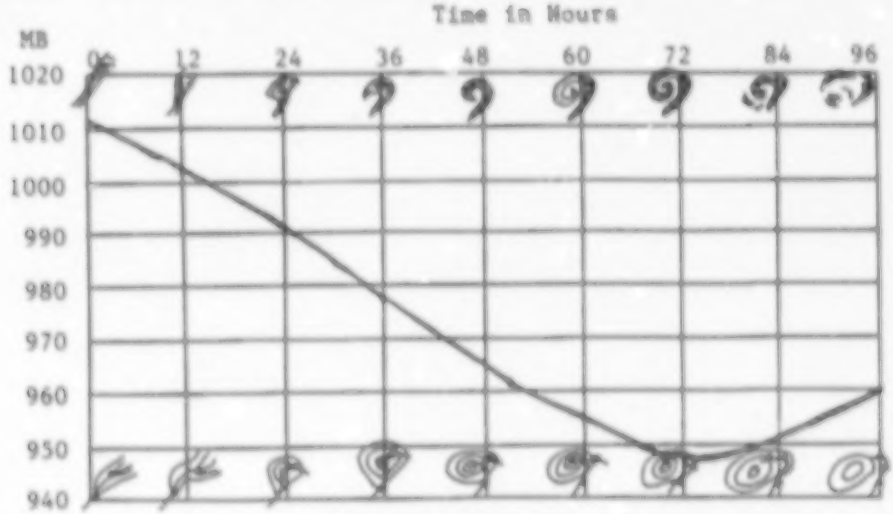

Figure 2. Cloud Patterns and Their Relationship to Minimum Surface Pressures & Pressure Patterns

In order to illustrate how the procedure works, a short segment illustrating 12 hour changes in cloud patterns and the relationship to surface pressures is presented as Figure 3.

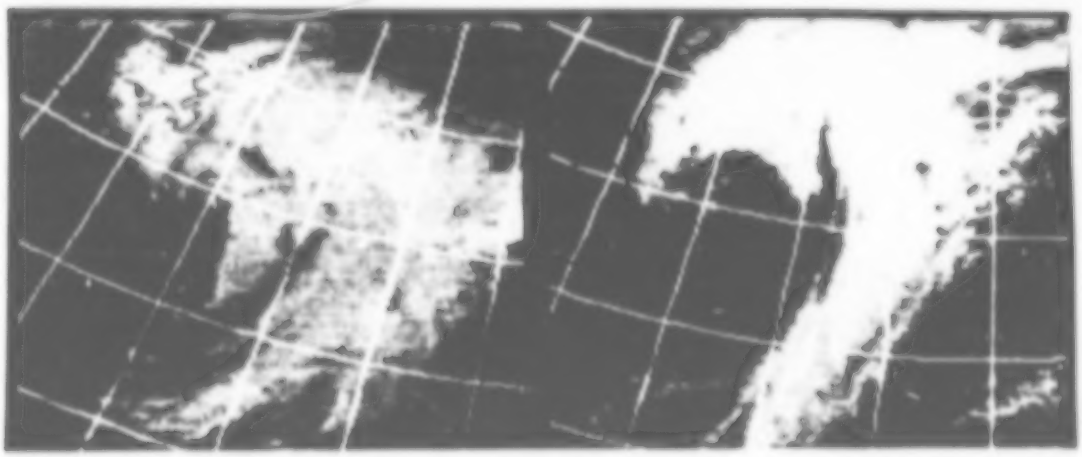

Figure 3. 10 January 00GMT 10 January 12GMT

In Figure 3, the left side image for 00GMT has an NMC analyzed pressure of 980mb. The satellite cloud pattern pressure indicates a minimum pressure of 977mb. The adjusted NMC analysis indicates a central pressure of 980mb.

To properly use the technique, we have to compare the right hand image of 1200GMT with the one on the left to see what changes have taken place in the cloud patterns associated with the storm. Table 1 is used to indicate whether further deepening has occurred.

The one deepening factor is the increase in curvature to the comma cloud. Another less noticeable one is the enhancement of the cumulus near the circulation center. These two indicators reveal deepening of the storm. Using the cloud pattern and the pressure curve of Figure 2, a minimum pressure of 973mb is indicated. The corresponding adjusted NMC pressure is 974mb, while the analyzed minimum pressure was 980mb. Notice that the NMC analysis did not lower the pressure, even though the cloud pattern changes and the adjusted analysis indicated further deepening.

CONCLUSION

The results of the test show that a definite relationship exists between cloud patterns and minimum surface pressures and pressure patterns. The storms may not always fall on the curve, since they may develop more rapidly or slower than the average curve. The cloud pattern will, however, reflect the minimum cyclone pressures as indicated by the curve, although the time interval between changes may vary, because of the rate of development of the cyclone.

The curve of figure 3 is for full latitude cyclones. These are the ones that develop along a frontal band and proceed through the entire cyclogenesis cycle. Other types of storms were studied. These included barotropic developments. These are storms that develop in the cold air and proceed through the cyclogenesis cycle remaining cold air systems. Another type studied, was a limited latitude development. This is one where the low moves eastward or slightly southeastward. These systems generally have central surface pressures that are higher than the full latitude systems for the same cloud patterns.

ACKNOWLEDGEMENTS

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L'INTELLIGENCE ARTIFICIELLE EN MÉTÉOROLOGIE: LA RÉALITÉ

par A. Cotnoir
Service de l'environnement atmosphérique, Direction de la formation

Résumé

Depuis le début des années quatre-vingt, on entend de plus en plus parler de l'arrivée de l'intelligence artificielle en météorologie. De quoi sont composés ces applications de l'intelligence artificielle: les systèmes experts? Comment simule-t-on la connaissance et le raisonnement du prévisionniste? Quel est le rôle potentiel de l'intelligence artificielle en prévision du temps? Voici les quelques unes des questions abordées par l'auteur tout au long du texte.

Abstract

Since the early 1980's, the arrival of Artificial Intelligence (AI) in meteorology is gradually gaining impetus. What are the particular applications of AI called Expert Systems? How do we simulate the knowledge and reasoning processes of a forecaster? What is the potential role of AI in forecasting? These are some of the questions approached in this discussion.

HISTORIQUE

On peut situer les racines de l'intelligence artificielle au 17^{ième} siècle. A cette époque Leibniz (1646-1716) avait exprimé l'idée de représenter et simuler le raisonnement humain au moyen de méthodes mathématiques. A ce propos, il écrivait:*"While I was yet a boy with a knowledge only of common logic, and without instruction in mathematics, the thought came to me, I know not by what instinct, that an analysis of ideas could be devised, whence in some combinatory way, truths could arise and be estimated as though by numbers" (Elementary Rationis)* (Brachman et Lévesque, p XIV).

Il fallut toutefois attendre l'avènement des premiers ordinateurs durant les années soixante pour que ce domaine prenne son réel essor. Après quelques échecs dus à l'ampleur du domaine choisi, par exemple lors des recherches en compréhension du langage naturel, on décida de se restreindre à des domaines précis d'application (médecine, géologie, etc). C'est ainsi que naquit vers la fin des années soixante-dix, et au début des années quatre-vingt en météorologie, les premiers systèmes experts.

STRUCTURE DES SYSTEMES EXPERTS

Les systèmes experts en météorologie, comme pour les autres domaines, sont élaborés à partir d'un programme informatique. En météorologie, ce programme est consacré à la simulation du raisonnement d'un prévisionniste ayant à procéder à une prévision. Ce programme est généralement écrit à l'aide de langages dédiés à l'intelligence artificielle comme LISP et PROLOG, mais peut également être rédigé en "C" ou même en FORTRAN.

Ces programmes sont composés (figure 1) de trois parties principales. Une partie réservée au stockage du savoir du domaine traité (la météorologie) sous forme de règles ou d'éléments de connaissances selon le choix de la représentation de la connaissance. On appelle cette section la *base de connaissances* et elle peut être assimilée, par analogie avec le cerveau humain, à la *mémoire à long terme* du système expert. Une autre section sert à emmagasiner les données actuelles utiles au fonctionnement du programme, par exemple prévoir les éléments du temps, ainsi que les données issues du processus de raisonnement. On nomme cette section la *base de faits* ou, par la même analogie, *la mémoire à court terme* du système expert. La dernière des trois parties consiste en un sous-programme dont le rôle est de tirer profit de la connaissance et des données résidant dans le programme et de construire le raisonnement souhaité, par exemple procéder à la prévision d'un élément du temps. On appelle ce sous-programme le *moteur d'inférence* .

A la base de connaissances, base de faits et moteur d'inférence se greffent parfois d'autres éléments assurant le fonctionnement du programme comme par exemple une *interface vers l'utilisateur* qui permet

à celui-ci une utilisation conviviale du programme et une *interface à l'architecte* qui permet au concepteur de modifier aisément le contenu du programme.

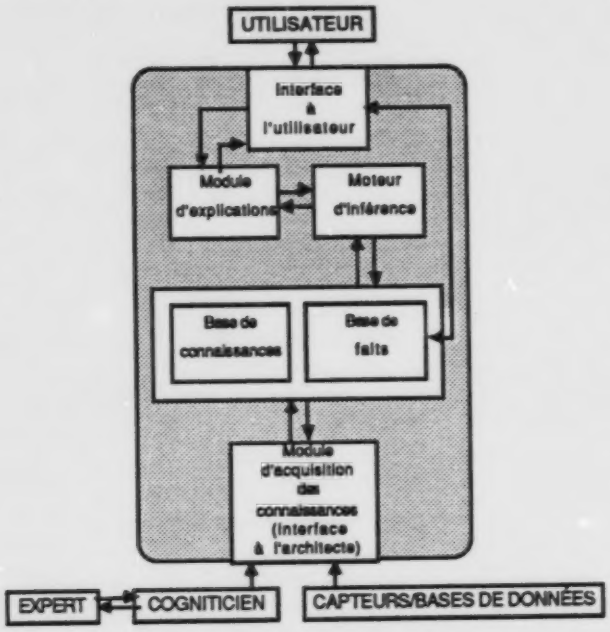

Figure 1 Structure des systèmes experts

REPRÉSENTATION DE LA CONNAISSANCE

Afin d'intégrer le savoir dans la base de connaissances, il est nécessaire de coder d'une façon quelconque ce savoir. Il existe plusieurs approches à cette fin toutes issues de la logique formelle. Les représentations les plus utilisées sont: la représentation en "si.....alors" ou *règles de production* et la *représentation en objets structurés.*

Les règles de production

Celles-ci ont la forme suivante:

Forme:	Si	**(condition)** alors	**(conséquence)**
Exemple:	Si x accroît l'humidité relative alors x produit des nuages bas de couche limite		
Règle:	Si la turbulence accroît l'humidité relative alors la turbulence produit des nuages bas de couche limite		

Elles permettent, par comparaison entre la condition de la règle et les données existant dans la base de fait, d'éliminer les règles non-applicables et d'ainsi construire le raisonnement.

La représentation en objets structurés

Il s'agit ici d'une représentation de la connaissance qui s'appuie sur la prémisse que l'humain mémorise une nouvelle situation ou s'adapte à une situation en utilisant une structure de pensée faisant appel à une collection d'objets simples et indépendants (Brachman et Lévesque 1985). Elle permet alors de développer une représentation de la connaissance qui répond au point de vue suivant: *"la pensée débute toujours avec une image partielle et imparfaite de la situation et évoluera ensuite progressivement vers une perception plus complète (mais toujours imparfaite) de la réalité"* (Kuhn 1962). Ceci a l'avantage de rendre possible une connaissance approximative de la réalité en lui attribuant des valeurs par défaut.

Par exemple, si le prévisionniste ne peut connaître la hauteur de la couche limite à un certain moment, il peut lui attribuer, par défaut, une valeur de 500 mètres.

Les éléments de connaissances sont représentés au moyen de *schéma*. Un *schéma* se compose *d'attributs* ou *fentes* représentant les noms des propriétés de cet élément de connaissances. Ainsi, à la figure 2, *vitesse et hauteur* représentent deux attributs pour le *mouvement vertical dynamique au sommet de la couche limite* . Les *attributs* contiennent également des *facettes* qui permettent de cerner la définition de l'élément de connaissances. Par exemple, la facette *"limite"* contient les valeurs correspondant à l'intervalle de validité de la *vitesse* du *mouvement vertical dynamique au sommet de la couche limite, "source"* indique la provenance de cet élément (modèles numériques, expérience du prévisionniste,etc), *"exactitude"* exprime le degré de confiance envers la valeur de l'élément de connaissances. De plus, un schéma fait partie d'une *hiérarchie* et est relié par des pointeurs à des schémas plus globaux. Par exemple à la figure 3, le *profil du mouvement vertical en-dessous de 3 kilomètres* est inclus dans une hiérarchie. Il est relié par un pointeur au *mouvement vertical dynamique au-dessus de la couche limite* et *mouvement vertical dynamique au sommet de la couche limite.* Il représente un schéma plus global que les deux autres éléments de connaissances et se nourrit, au besoin, de l'information disponible à partir des autres membres de la hiérarchie.

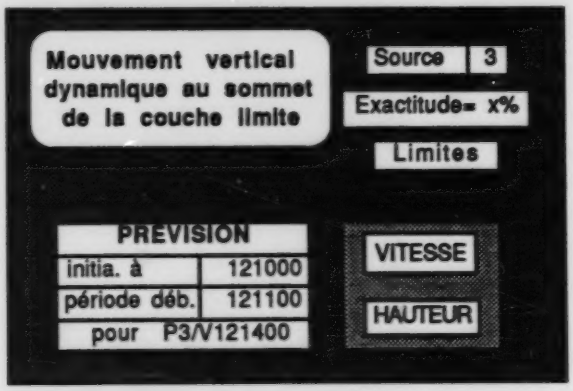

Figure 2 Représentation graphique d'un schéma

Cette façon de représenter la connaissance permet de procéder à la solution du problème (diagnostic et prévision) en utilisant une collection d'éléments simples et indépendants conforment à la structure de pensée décrite au début de cette section.

REPRÉSENTATION DU RAISONNEMENT

Afin de construire les éléments de connaissances ou règles composant la base de connaissances, il est nécessaire de développer un modèle descriptif du raisonnement. A cette fin, il existe actuellement deux grandes approches dans ce domaine.

Une première approche propose que la composition des règles devrait être basée essentiellement sur un modèle de raisonnement faisant appel à la reconnaissance de patrons. Ce modèle a été étudié en détail par G.A. Klein (1986, 1987) lors de recherches effectuées auprès de décideurs soumis à des contraintes équivalentes à ce que doivent vivre les prévisionnistes (contraintes de temps, d'équipements et/ou de qualité de l'information). Les résultats indiquent que ces décideurs se fient à leur expérience et à leur capacité de reconnaître une situation comme familière (reconnaissance de patrons) afin de résoudre un problème. Ce raisonnement par reconnaissance de patrons est à la base des règles de prévision (règles du pouce) utilisées depuis longtemps en météorologie opérationnelle. Le principal défaut relié à l'utilisation de ces règles est qu'elles ne sont pas aisément transférables d'un endroit de prévision à un autre. De plus, il semblerait, qu'à partir des ordinateurs actuellement disponibles, l'on ne puisse aisément simuler le raisonnement par reconnaissance de patrons.

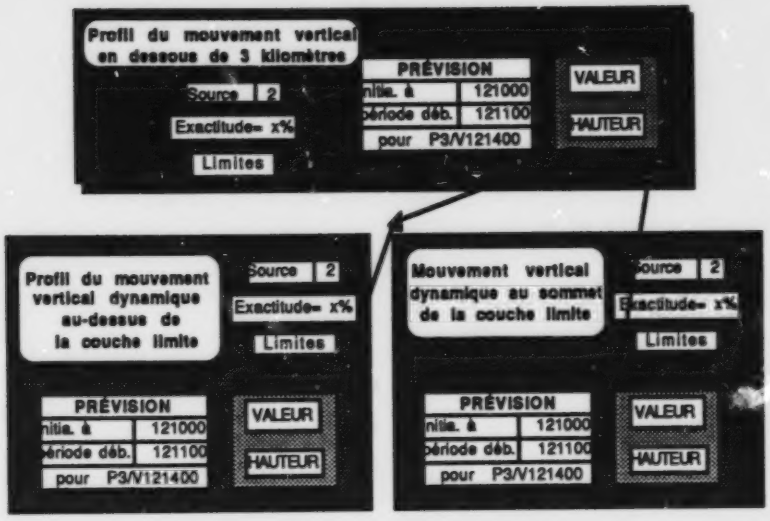

Figure 3 Schémas reliés par hiérarchie

Une seconde approche propose qu'il serait approprié de développer des règles en faisant appel au raisonnement analytique puisque les ordinateurs ne sont pas soumis aux mêmes contraintes que les humains (temps, équipements, qualité de l'information). C'est à dire que le raisonnement doit générer le plus grand nombre possible de solutions et que, suite à une réflexion analytique sur les différentes solutions générées, le décideur doit choisir la meilleure solution. Dans ce modèle, l'élaboration des règles se fait essentiellement à partir des principes physiques issus de la théorie météorologique. Toutefois dans certains cas, lorsque les données ou connaissances actuelles des processus physiques sont insuffisantes, on utilisera des règles issues du raisonnement par reconnaissance de patrons (règles semi-empiriques).

ROLE DE L'INTELLIGENCE ARTIFICIELLE EN PRÉVISION DU TEMPS

Jusqu'à maintenant l'essentiel des efforts de recherches se sont portés sur l'élaboration de systèmes experts. S'agit-il de la seule utilisation possible de l'intelligence artificielle en prévision? Pour répondre à cette question on peut se référer à l'étude de Racer et Gaffney (1984) sur l'utilisation de l'intelligence artificielle dans le processus de prévision et le travail du prévisionniste (figure 4).

En premier lieu, l'intelligence artificielle pourrait être utilisée au niveau des étapes de collecte, décodage et analyse des données disponibles (radars, satellites, modèles, observations, etc) en suggérant une approche structurée à la démarche du prévisionniste, sorte de liste de vérification de la procédure à suivre. Lors de ces mêmes étapes, elle pourrait orchestrer l'interaction avec les différentes données disponibles et ceci selon les besoins du prévisionniste. Puis elle pourrait servir d'expert conseil au niveau du diagnostic et du pronostic en simulant le raisonnement d'un ou plusieurs experts. Elle pourrait également aider à la formulation des prévisions en automatisant la rédaction des textes dans les formats requis. Finalement, l'intelligence artificielle pourrait effectuer la surveillance du temps, avertissant au besoin le prévisionniste de tout changement important dans les conditions du temps.

On voit que, selon cette étude, le rôle de l'intelligence artificielle en météorologie ne se limite pas à son unique utilisation en vue de simuler l'expertise. Elle comprend plutôt une gamme complète de fonctions d'aide au prévisionniste se retrouvant tout au long du processus de prévision. Cette perspective laisse entrevoir l'élaboration de systèmes jouant beaucoup plus le rôle de collègue prévisionniste dans les différentes étapes de la prévision, que celui d'un expert donnant son avis final sur le problème du jour. L'emploi de l'expression *"système collègue"* serait alors plus révélateur de l'intention des concepteurs.

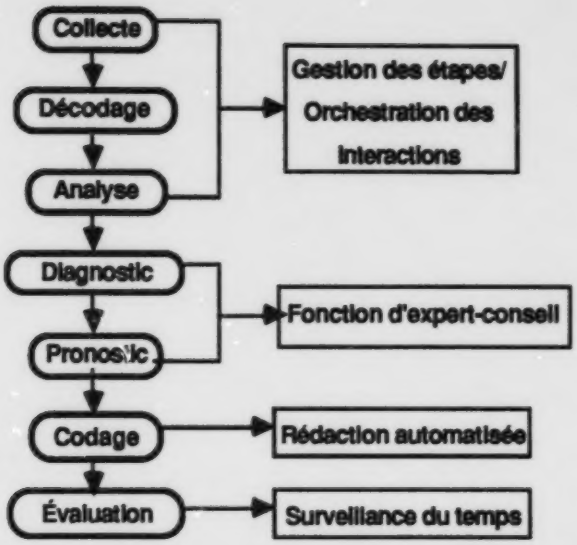

Figure 4 Intégration de l'intelligence artificielle dans le processus de prévision (adapté de Racer et Gaffney)

CONCLUSION

Les premières applications de l'intelligence artificielle en météorologie datent du début des années quatre-vingt. Ces premières applications, les systèmes experts, ne sont en définitive que des programmes informatiques dédiés à la simulation du raisonnement. Les systèmes experts se composent de trois parties principales: *la base de connaissances, la base de faits et le moteur d'inférence*, auxquelles s'ajoutent parfois des "options" telles que: *l'interface vers l'utilisateur et l'interface vers le concepteur.*

Afin de représenter la connaissance dans ce programme, on utilise diverses méthodes telles que: *les règles de production et la représentation en objets structurés.* En ce qui a trait à la représentation du raisonnement, il existe actuellement deux grandes approches: *le raisonnement par reconnaissance de patrons et le raisonnement analytique.*

Bien que les efforts de recherches actuels se soient concentrés, jusqu'à maintenant, dans l'élaboration de systèmes simulant l'expertise, il semble que les voies d'applications de l'intelligence artificielle se retrouvent tout au long du processus de prévision. Le système complet jouera alors beaucoup plus que l'unique rôle d'expert-conseil, il jouera celui de collègue du prévisionniste.

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AN EXPERT OPERATIONAL ADVISOR

by

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Abstract

We propose an 'expert operational advisor' to alleviate some inherent difficulties with weather forecasting. Its purpose is to produce a forecast, compare it with a terminal forecast, identify significant differences and then provide explanations of any such differences. The meteorological knowledge that we use to illustrate our ideas concerns the formation and dissipation of radiation fog at specific sites in the Maritime provinces of Canada. An hierarchially structured knowledge base, that contains several classes of rules for the prediction of an event as well as for providing relevant explanations, is used. This knowledge base updates a logical spread sheet designed to display data efficiently while at the same time providing a user-friendly interface. Case studies have been used to develop the system. A much broader design is then presented suggesting that our ideas are more general in application.

Nous proposons un 'expert conseil opérationel' pour alléger la tâche que représente la prévision du temps. Le but du système est de produire une prévision, de comparer celle-ci avec une prévision à l'aviation (pour un aéroport), d'identifier les différences significatives et d'expliquer ces différences. Le domain météorologique utilisé pour démontrer nos idées se limite à la formation et dissipation de brouillard de radiation à des sites spécifiques dans les provinces maritimes du Canada. On utilise une base de connaissances contenant plusieurs classes de règles, non seulement pour faire une prévision mais, aussi, pour donner des explications pertinentes. Cette base de connaissances est arrangée dans une structure hiérarchique et met à jour un chiffrier électronique logique qui a pour but de permettre à l'usager de visualiser et de manipuler les données d'une façon efficace. Des études de cas ont été utilisées pour développer le système. Enfin, un projet de plus grande envergure est envisagé pour suggérer que nos idées peuvent être appliquées d'une façon plus générale.

INTRODUCTION

Weather forecasting is a broad and complex domain of expertise that integrates pattern and feature recognition, physical modelling, planning, natural language processing, detailed local knowledge, common sense and human interaction. Each of these facets is individually difficult and the subject of ongoing research in artificial intelligence. The full scope of weather forecasting is thus a rather broad topic for current expert systems and artificial intelligence technologies.

Currently many researchers are attempting to identify forecasting subproblems to which the application of expert systems technology may be appropriate [eg. Conway 1989]. Prototypes have been reported in the area of advective fog formation [Dyer 1988], maritime visibility obscuration [Peak and Tag 1989], terminal forecasting [Zwack and Cotnour 1988] and [Zwack et al. 1989]. Tremant [1989] describes a field tested system that forecasts sea fog. He points out that it is as difficult to forecast 'no fog' as it is to forecast 'fog'. A common problem facing all such systems is that of acceptability. To be acceptable an expert system must offer more than expert quality conclusions. It is essential that it be easy to use, displays pertinent information and requires a minimum of time and effort (convenience and speed, [Conway 1989]).

The proposed system, uses an hierarchially structured knowledge base and a logical spread sheet to compute and represent a forecast as well as to facilitate the human-computer interaction. While terminal forecasts are being prepared, a prediction routine is performed and results are entered into the logical spread sheet. Relevant forecast parameters are compared with those in the corresponding terminal forecast. If significant differences are found, analytical routines search for factors that could cause the discrepancy. Explanatory routines access the knowledge hierarchy and present these factors to the forecaster. Prior to the performance of the prediction routine, the forecaster may opt to overwrite the default values used by the system. These default values are based on the current observations and climatological data. This option is also available following the explanatory stage to allow experimentation with forecast values. At successive hours, observations are incorporated into the logical spread sheet to generate updated forecast parameters.The meteorological knowledge that we use to demonstrate these ideas concerns the formation of radiation fog at Fredericton, New Brunswick, in the Maritime region in Canada. An aviation parameter was required for this study and radiation fog was selected because it is relatively simple. The same principles apply to other forecast parameters.

We begin by describing the structure of the knowledge base and the logical spreadsheet showing how this spreadsheet is updated by the knowledge base. We also show how the spreadsheet acts as a user friendly interface. We then give the details of the case studies that are used to develop the system. We then describe the explanation and modelling aspects of the system and show how explanations are generated using rules, the knowledge hierarchy and the contents of the logical spread sheet. Finally we show how this research relates to a possible complete expert computing system for aviation forecasting and specify some limitations of the current study and directions for further research.

KNOWLEDGE STRUCTURE

Most of the meteorological knowledge used by the system is represented in an hierarchy of condition action rules as shown in figure 1. This hierarchial structure facilitates extension of the system to cope with further forecast parameters (for example, more comprehensive wind prediction rules could be added), and enhances the adaptability (for example, more site dependent topographical rules could be added for other weather stations in the Maritime provinces). This hierarchial structure is to be used by the explanatory mechanisms, as necessary.

Data used consists of hourly observations and tephigrams and is reflected in the structure and function of the system. Less use is made of numerical model data due to the short term nature of terminal forecasts. Satellite images are not used because of the difficulty of accessing and processing this data.

System control centers on a logical spread sheet, part of which is displayed in table 1. Hourly data is entered automatically into the spread sheet as it becomes available. Forecast

values are determined by the inference engine using rules that access and modify the logical spread sheet. Typically, data in the columns to the left of the current time column is exact (as taken from the hourly observations), while data to the right of the current time column results from the prediction routines. A similar table results from an analysis of the terminal forecast.

Other knowledge and algorithms are accessed by the rules. For example, an approaching ridge of high pressure is an important factor in radiation fog prediction. To imitate a forecaster's visual interpretation of a surface map, this system uses available hourly data to compute the position of a surface ridge line at the times at which the maps are plotted. Orientation and motion of this ridge line is computed and extrapolation techniques are employed to estimate the arrival time at the site.

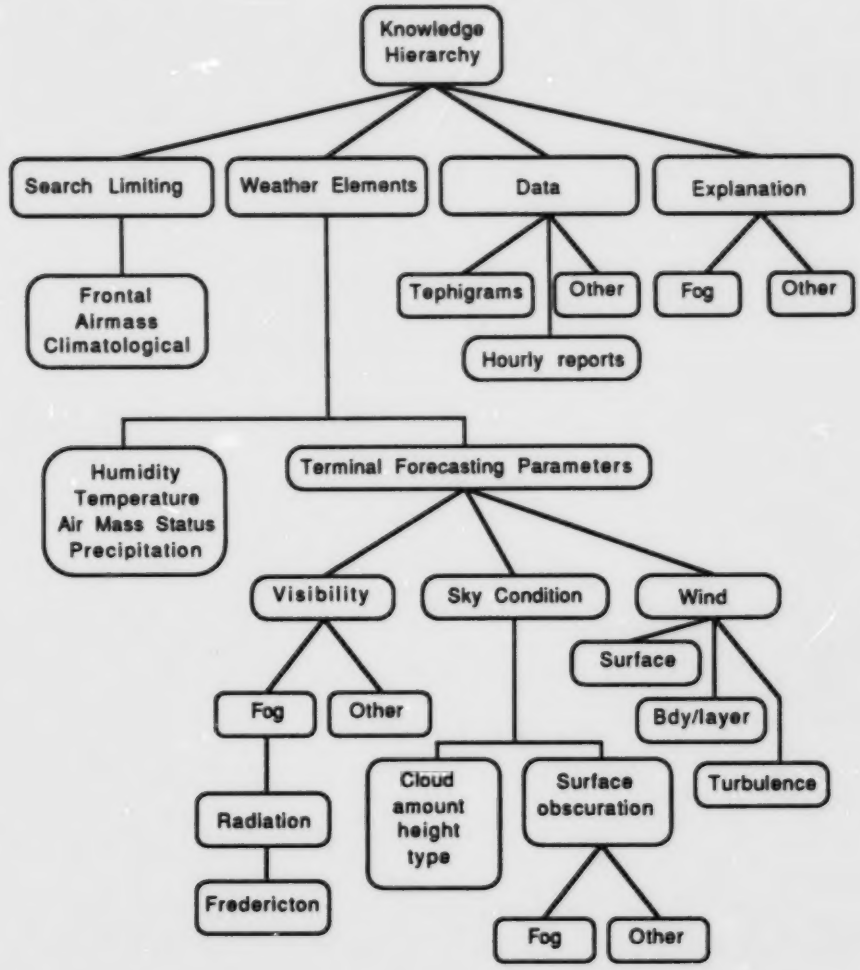

Fig. 1. Knowledge structure used in the 'Expert Operational Advisor'. Elements in this hierarchy represent the knowledge acquired from operational forecasters rather than textbook information.

Table 1. The logical spread sheet.

Fredericton, October 24-24, 1989.

	16Z	17Z	18Z	19Z	20Z	21Z	22Z	23Z	24Z
Pressure.	27.5	27.2	27.4	27.5	27.7	28.1	28.9	29.4	30.1
Cloud amount.	1	0	1	1	0	0	0	0	0
Visibility. . . .	15	15	15	15	15	15	15	15	15
Obscuration. .	nil	nil	nil	nil	nil	nil	nil	nil	nil
Wind dir	300	280	290	300	270	270	000	190	210
Wind speed. . .	8	8	9	7	7	4	0	3	2
Temperature .	9	9	10	11	11	10	7	4	3
Dew Point . . .	0	0	- 1	- 1	- 1	- 1	- 1	- 2	- 2

CASE STUDIES

Case studies have been used to assess the potential of the proposed system. Figure 2 shows the main line of reasoning followed in the case studies. Each branch in the tree is associated with a class of rules in the knowledge base. Each branch also allows a range of certainty from unlikely to likely. The explanation of the difference between the terminal forecast and the forecast produced by the system is also determined in part from this structure. This structure is more complex than that supported by simple decision tree mechanisms.

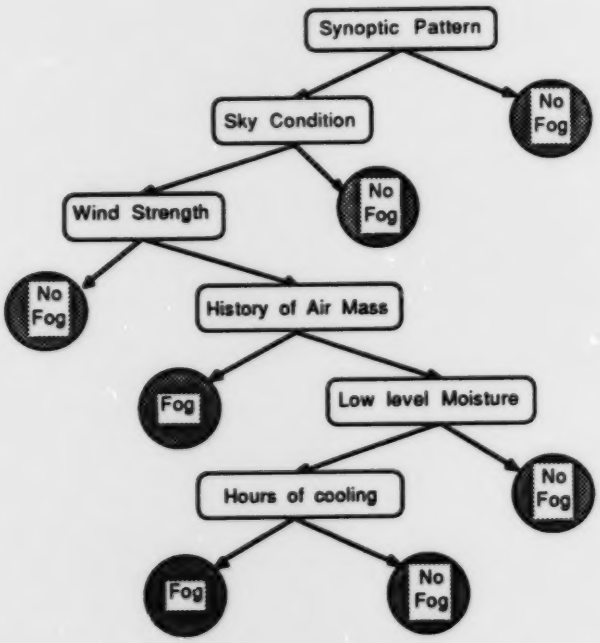

Fig. 2. The diagram represents the way the rules in the knowledge hierarchy are used to produce the radiation fog forecast. This method results from a survey that was conducted to determine how operational forecasters predict radiation fog.

To begin a case study, the relevant data is accessed by the logical spread sheet. At forecast time, the prediction routine shown in figure 2 is performed. The first step requires an assessment of synpotic conditions by accessing rules in the corresponding class.

Case study 1 includes data from October 23-24, 1989, with morning fog on October 24th being considered. A ridge line is detected in a NNE-SSW orientation 120 miles west of Fredericton at 2:00 p.m. on October 23rd. Calculations indicate an expected time of arrival at the site of 8:00 p.m. on October 23rd. Based on this timing 'no fog' is predicted at Fredericton on October 24th. Similarly, 'no fog' is indicated in the evening terminal forecast. As no significant difference occurs between the forecasts, the explanation routines are not invoked.

Actual observations report no obscuration to visibility on October 24th other than a restriction of 5 miles between 7:18 a.m. and 8:00 a.m. with a remark stating that 12 miles visibility could be observed eastward. Although slightly less than perfect results obtained by the expert system, this result is judged too insignificant to warrant further effort at this time.

Case study 2 spans September 3-4, 1989. A broad ridge of high pressure appears on the surface map at 2:00 p. m. on September 3rd. A ridge line over the Great Lakes is moving eastward remaining west of Fredericton on the morning of September 4th. This is a favourable synoptic pattern for radiation fog and reports showing clearing skies indicate enhanced fog potential. Diminishing wind strength continues to support possible fog formation. Historically, upstream stations in this air mass reported fog while Fredericton showed little visibility obscuration previously. Slightly higher amounts of low level moisture may reach Fredericton as this air mass pushes eastward. Finally, sufficient hours are available for required cooling. 'Fog' is thus predicted to form prior to sunrise.

'No fog' is forecast in terminal forecasts prepared on the evening of September 3rd. and at midnight. This discrepancy is revealed and the logical spreadsheet triggers explanatory routines that suggest reasons for the discrepancy based on the above information.

Actual data showed that 'fog' occurred between 6:28 a. m. and 7:30 a. m. on September 4th, reducing visibility to 1/2 mile for 25 minutes. A cursory glance at this situation does not suggest radiation fog as a likely event. It is therefore an ideal situation for using such a system as a forecast aid.

EXPLANATION AND MODELLING MECHANISMS

Explanatory mechanisms are to play a major part. Without clear explanations results lack credibility. These mechanisms are to be triggered when a discrepancy exists between the results produced by the system and the contents of the terminal forecast. Based on the details of the forecast, the system will attempt to diagnose the factors responsible for the differences. A simple case consist of a strong wind forecast overnight in a terminal forecast compared to much lighter winds in the system forecast. A forecaster may choose to overwrite forecast wind values in the logical spread sheet to reduce the discrepency.

Initially a brief statement concerning the differences will be displayed. Additional information can be obtained if desired. Additional information will cause an explanation of the factor's importance supported by actual data for the specific case.

DISCUSSION AND CONCLUSIONS

The purpose of the current research is not primarily to produce an operational and training tool dealing with radiation fog at one airport. The major idea is to produce a 'testbed' to explore the idea of explaining the difference between a terminal forecast and a forecast produced by an 'expert operational advisor'. Plans include the incorporation of further forecast parameters and a detailed analysis of the user interface and the utility of such systems in terminal forecasting. A goal is to study the feasibility of a system that will provide expert opinion on the quality of a set of terminal forecasts prepared by a meterologist. Such an extensive system could provide a critique based on local expertise, climatological and realtime data; operate with minimal prompts to the user and produce explanations of differences at any stage as requested by the user. The system is currently being implemented using Arity Prolog on the IBM PC. Various utilities from the Arity Advanced Toolkit, including the Arity Logical Spreadsheet have been drawn upon.

Recent advances in numerical weather prediction coupled with satellite pictures and Doppler radar images have improved weather forecasts. The ability of meteorologists to interpret this data and combine it with their local expertise results in high grade customer specific forecasts. This expertise is particularly valuable in short-term forecasts that are of major concern to the aviation industry. We propose a particularly appropriate way of applying expert system technology in an advisory capacity to terminal forecasting. Capturing knowledge of this kind will be of great benefit to all forecasters. New forecasters will have immediate access to detailed expert advice in addition to that available in the initial training period that cannot include all events of the annual weather cycle. Case studies indicate the feasibility of such an advisory expert system with a flexible structure that is capable of more general application. Clearly these ideas need to be field tested.

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EXPERT SYSTEMS FOR QUALITY CONTROL AND MARINE FORECAST GUIDANCE*

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ABSTRACT

Two automated expert systems have been developed by the National Oceanic and Atmospheric Administration (NOAA). One is a system for marine analysis and real-time quality control (SMARTQC) of marine data. The second system is designed to support the high seas forecasting of operational meteorologists by generating a narrative from forecasts based on the National Meteorological Center's (NMC) global atmospheric and ocean wave prediction models.

Deux systèmes experts automatisés ont été développés par le "National Oceanic and Atmospheric Administration" (NOAA). L'un est un système d'analyses en mer et de contrôle de qualité des données marines (SMARTQC). L'autre système assiste les prévisionistes maritimes en générant des prévisions maritimes écrites basées sur le modèle numérique de prévision de l'état de la mer et le modèle global du NMC.

INTRODUCTION

National weather centers are faced with two challenges which greatly affect their marine operations. The first is the time critical quality control of the large amounts of marine observations available for ingestion into numerical atmospheric and ocean models. The second is the timely dissemination of both the QC'ed data and the forecast guidance based on the output from these numerical models.

Two automated expert systems have been developed by NOAA with applications to marine meteorology. One, SMARTQC, provides marine analyses and real-time quality control. This system checks and corrects observation platform coded locations, measurement biases, and digit transpositions. In addition to generating a summary of checks and changes by platform, SMARTQC allows for querying individual platforms and gives reasons for changes.

The second system is designed to assist forecasters in preparing marine forecasts which are broadcast to users at sea in a narrative

*OPC Contribution No. 42

format. The program tracks and extracts information about significant over water weather systems from forecasts based on the NMC's global atmospheric and wave models. From this information specific words and phrases are selected and assembled by the computer to describe cyclone position, intensity, and track; areas of high wind and waves; fog and low visibility regions; and superstructure ice accretion areas.

QUALITY CONTROL OF MARINE SURFACE DATA

The spatial and temporal coverage of the existing ocean observing network is sparse and expensive compared with equivalent measurements over land. The QC of marine observations are presently done using the QUality Improvement Performance System (QUIPS) (Richardson and Reilly,1989). This interactive VAX-based system automatically assists in the QC of one parameter, sea-level pressure (SLP). In this system an automatic check compares the SLP observation to an interpolated first guess field from an atmospheric assimilation scheme or model. A report that departs from the first guess by a set amount is flagged as questionable.

While QUIPS takes advantage of the judgement of the QC meteorologist running the system, it is very labor intensive and the number of observations which can be QC'd will diminish as the number of parameters to be examined grows. SMARTQC is a first step toward making the QC of large amounts of marine data manageable. A step that captures individual expertise while eliminating subjectivity. SMARTQC is an automated version of the "Interactive Monitoring/QC" module shown in Figure 1. The flow diagram for SMARTQC is illustrated in Figure 2.

The history and SMARTQC explanations and decisions for platform SQPP are shown in Figure 3. A latitude/longitude of 5.8°S/32.7°W was reported on day 21 at 00Z. The measured pressure of 1017.2 mbs was 3.8 mbs higher than the interpolated first guess. These values are shown in line "Hist 1:". Looking at line "Plat QC:" of Figure 3 we see that the initial criteria, 4 mb departure, is met, the measured pressure is 4.2 mbs higher than the first guess. The position of ship "SQPP" is consistent with its history. Based upon the history there is a 3.33 mb bias. This bias is very consistent (standard deviation of the bias is 0.50 mbs). Since the corrected pressure (1016.47 mbs) is within 4 mbs of a buddy (neighbor) "GHYP" the corrected pressure is accepted by SMARTQC.

SMARTQC made the same decisions as the analyst in 74 percent of the 55 comparison cases. For the remaining cases, SMARTQC performed as well as, and in some cases, better than the analyst. SMARTQC made its decision in a fraction of the time that it took the analyst.

Plans include expanding SMARTQC to include air and sea surface temperature and wind speed. Consistency checks among these variables will be automatically done. SMARTQC changes will be

automatically assigned probability value and interfaced into QUIPS. The analyst will need only to review changes outside assigned thresholds.

COMPUTER-WORDED MARINE FORECASTS

NOAA has the responsibility to provide weather warnings and forecasts to vessels on the high seas (open ocean). Typically these forecasts are distributed to marine users via radio in a narrative format. A computer program has been developed to assist forecasters in preparing such marine forecasts (Richardson, et al., 1989). The program extracts information about significant over-water weather systems from forecasts of the NMC forecast models and then selects and assembles "computer-worded" words and phrases to describe weather and wave conditions over the high seas.

Warnings

The warnings portion of the message contains forecasts of storms and other significant weather systems with associated winds of 35 kts or greater. When several systems exist, the system with the highest wind speed is listed first with other systems following in order.

Central pressure and location of the system at the initial time of the forecast and at the 24- and 36-h projections are given. The direction of movement and speed of the system is also forecast. Maximum wind and wave conditions are forecast and referenced from the center of the weather system. In addition, averaged forecast wind and wave conditions are described. If there is no system, the word "none" is transmitted.

Synopsis and Forecast

This portion of the message contains a synopsis and forecast of weather systems with wind speeds less than gale force (less than 35 kt) but greater than 25 kts. Most of the wording for these systems are the same as for systems in the warnings portion of the message. However, the location of maximum wind and wave conditions and the average wind speed and wave height are not worded.

Computer-generated Matrix

A two-dimensional matrix of forecast times and meteorological and oceanographic related elements is formed. At each forecast hour (06, 30, and 42), the latitude and longitude of each low and high are entered. Also entered are the central pressure, the maximum and average wind speeds, and the relationship of the maximum wind speed from the center of each low and high. Wave heights are calculated from the maximum and average wind conditions.

Digital forecasts for the Atlantic Ocean are shown in a matrix format in Figure 4. These forecasts, which were extracted from an NMC atmospheric forecast model, are valid beginning 0600 universal time coordinate (UTC) February 21, 1990, and were available approximately 1 hour before the 1000 UTC issuance time. For each weather system, the five columns, from left to right, define the element, the unit of measurement of the element, and the forecast of the element at the first forecast hour and forecast hours 30 and 42 hours. Here the first forecast hour corresponds to the 6-hour projection of the NMC forecast from the 0000 UTC run.

Computer-wording

Digital forecasts are the basis for the computer wording. More than 100 different computer-stored words and phrases are used to construct forecasts and describe the type of weather system, intensity, location, movement, wind speed, and wave height.

The matrix in Figure 4 depicts one system. Figure 5 contains the computer-worded forecast which was generated on a VAX workstation from the matrix. Shown in Figure 6 is the forecast issued by Weather Service Forecast Office Washington. The computer-worded guidance compares favorably with this official forecast. Reduced visibility and superstructure icing are not shown in this matrix but may be entered manually and automatically worded. The VAX workstation makes it possible to interactively change and automatically reword the forecast.

ACKNOWLEDGEMENTS

We are very grateful to the many people who have provided guidance and encouragement for these projects. QUIPS and SMARTQC were developed under contract to COMPASS Systems, Inc., and Computer Communications and Graphics Associates, Inc., respectively.

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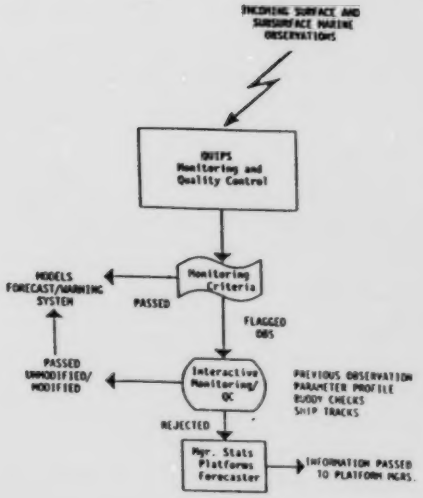

Figure 1. Data flow and monitoring/ QC activities.

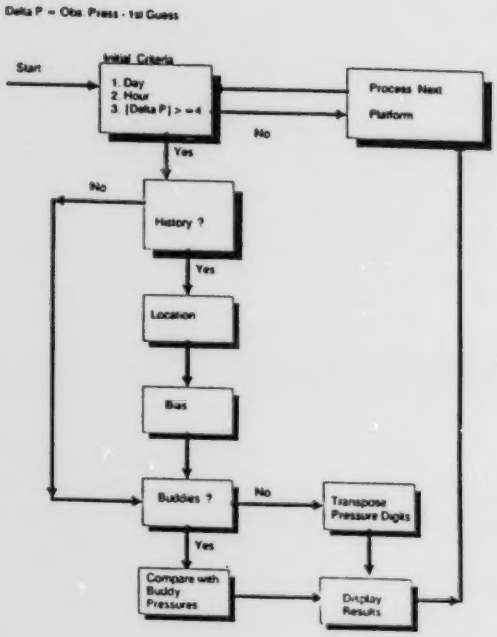

Figure 2. Flow diagram for SMARTQC.

```
Hist  1:      SQPP -5.80 -32.70 21.00 0.00 3.80 1017.20
Hist  2:      SQPP -8.50 -34.10 21.00 12.00 3.40 1018.00
Hist  3:      SQPP -9.90 -34.70 21.00 18.00 2.80 1017.80

Plat QC:      SQPP -11.30 -35.30 22.00 0.00 4.20 1019.80

GHYP -13 -35 89082200  20 1018.60

SQPP (SHIP): Position consistent with history.

Consistent Bias: 3.33
Standard deviation of the Bias: 0.50
Bias has been applied.
Corrected pressure is 1016.47 mb

This value agrees with the majority of the buddy values.
```

Figure 3. History and SMARTQC explanations.

HIGH SEAS COMPUTER-WORDED FORECAST FOR
NORTH ATLANTIC NORTH OF 32N AND WEST OF 35W
VALID 06Z FEB 21 1990 FOR THE NEXT 36 HOURS

ELEMENT	UNITS	06Z	06Z	18Z
TYPE OF WEATHER SYSTEM		LOW		
LAT/LONG	DEG	49N/39W	58N/28W	63N/23W
CENTRAL PRESSURE	MBS	964	964	968
MOVEMENT	DEG KT	3 /28	4 /27	3 /29
MAX WIND SPEED	KT	50	45	45
MAX WAVE HEIGHT	FT	25	30	30
LOCATION OF MAX WIND	DEG NM	20 /258	10 /652	12 /705
AVG WIND SPEED	KT	30		
AVG WAVE HEIGHT	FT	15		
REDUCED VSBY	T LA/B	LA	****/****	
	L LG/R	LG	****/****	
SUPERSTRUCTURE ICING	T LA/B	LA	****/****	
	L LG/R	LG	****/****	

Figure 4. Matrix of digital forecasts for the Atlantic Ocean.

TAAOO KNFD 211000

HIGH SEAS FORECAST
NATIONAL WEATHER SERVICE WASHINGTON D.C.
1000 UTC WED FEB 21 1990
NORTH ATLANTIC 32N TO 65N AND WEST OF 35W
FORECAST VALID 1800 UTC THU FEB 22 1990

WARNINGS.

STORM CENTER 964 MBS 49N 39W MOVING NORTHEAST 28 KTS AND WEAKENING DURING THE NEXT 36 HRS. FORECAST GALE CENTER 968 MBS 63N 23W. WINDS 50 KTS AND SEAS 25 FT WITHIN 260 NM SOUTH OF THE CENTER. WINDS AND SEAS DIMINISHING DURING THE NEXT 24 HRS. ELSEWHERE WINDS 30 KTS AND SEAS 15 FT.

SYNOPSIS AND FORECAST.

EXCEPT AS DESCRIBED IN WARNINGS WINDS 25 KTS OR LESS AND SEAS LESS THAN 9 FT WILL CONTINUE DURING THE FORECAST PERIOD.

Figure 5. Computer-worded forecast generated from matrix shown in Figure 4.

TTAAOO KNFD 210937
HIGH SEAS FORECAST
NATIONAL WEATHER SERVICE WASHINGTON D.C.
1000 UTC WED FEB 21 1990

NORTH ATLANTIC NORTH OF 32N TO 65N WEST OF 35W
.FORECAST VALID 1800 UTC THU FEB 22 1990

WARNINGS.
STORM 49N 42W 964 MB AT 0600 UTC MOVING NE 25 KTS. WITHIN 300 NM N AND 1100 NM S SEMICIRCLES WINDS 35 TO 60 KTS AND SEAS 15 TO 30 FT. FORECAST STORM E OF AREA. FORECAST WINDS 25 TO 45 KTS SEAS 12 TO 22, FT NE OF A LINE 60N 50W TO 40N 35W.

DEVELOPING GALE 59N 95W 990 MB AT 0600 UTC MOVING E 15 KTS. FORECAST, GALE 59N 70W 980 MB. FORECAST WINDS 25 TO 35 KTS SEAS 8 TO 12 FT OF 40N AND W OF 60W.

SYNOPSIS AND FORECAST

HIGH PRES 39N 75W 1038 MB MOVING SE 30 KTS. FORECAST HIGH 34N 59W, 1033 MB.

Figure 6. Forecast issued by Weather Service Forecast Office Washington.

SWIFT AND KASSPR - AN OPERATIONAL TEST

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ABSTRACT

Artificial Intelligence technology is taking its first haltering steps in the Environmental Sciences arena and to date very little experience has been gained in using these systems in an operational environment, and very little comparative verification has been done.

Environment Canada has developed two experimental Artificial Intelligence systems for forecasting severe convective weather. The first of these, SWIFT (Severe Weather Intelligent Forecast Terminal) was developed under contract in 1987. It uses heuristical rules to modify a statistical predictor of convective weather developed by Strong, namely the SC4. The second system, KASSPr (Knowledge Augmented Severe Storms Predictor), was developed in-house by B. deLorenzis (developer) and J. Bullas (expert). It uses dynamic and thermodynamic predictive fields from the operational Finite-Element Model resident at the Canadian Meteorological Centre as input and attempts to emulate a modified Kansas-City technique to predict severe weather.

As an operational unit (Forecast Operations, Western Region, Atmospheric Environment Service) was involved in development of these systems, then an operational test was a natural step in that development. SWIFT was implemented in the Alberta Weather Centre for the 1988 and 1989 summer seasons in for an "operational" test. KASSPr was implemented in 1989.

The expert systems and the test methodology will be described. The results of the experiment will be reported from the point of view of lessons learned and overall verification.

BACKGROUND

The Alberta Weather Center in Edmonton, Alberta has a severe weather summer program dedicated to providing timely severe weather watches and warnings for during the summer; a similar program is in place at the Prairie Weather Center Winnipeg, Manitoba, which produces forecasts for Saskatchewan, Manitoba, and Ontario. A dedicated severe weather forecaster is on-site during daylight hours, conducts a full severe weather analysis and prognosis program based on a modified "Kansas-City" technique.

PURPOSE OF THE EXPERIMENT

The primary reasons for testing these systems in an operational office were as follows:

i) To gain experience in operating the systems in an operational environment.

ii) To gain information on the utility of the systems general as guidance to the operational forecaster.

iii) To perform an analysis of results to improve the skill of the systems.

However, since a control forecast was available, it was therefore possible to perform a relative verification between the expert systems and the human forecaster to gauge the relative skill of these systems.

SYSTEMS DESCRIPTION

The systems are described in detail by McLeod et al (1990). They will be described briefly below.

Severe Weather Intelligent Forecast Terminal (SWIFT)

SWIFT is a marriage of two previously-developed systems, namely METEOR developed by Elio and De Haan for the Alberta Research Council and PREFORMA, developed by Mc Donald-Dettwiler of Richmond, B.C.

SWIFT's knowledge base is based on a statistical algorithm called the synoptic index of convection or SC4 (Strong, 1979, 1983b). This index uses as input instability indices (Lifted Index and EGDEX) and two indicators of the synoptic situation (24 hour forecasts of 700 mb change and of 100-500 mb change). The output is a variable bounded (originally) from -3 to +5 with -3 being interpreted as forecast of no deep convection to +5 interpreted as a forecast of severe with the potential of larger than golf-ball sized hail.

SC4 data, surface moisture (Equivalent Potential Temperature) and parsed SA data are used to produce a graphical areal forecast of Severe Weather Threat Area and Initiation Area. A verbal explanation for each severe region is also produced.

SWIFT was implemented on a Xerox 1186 workstation. .

Knowledge Augmented Severe Storms Predictor (KASSPr)

KASSPr was developed in-house with Bruno deLorenzis (Toronto) the knowledge engineer and John Bullas (Edmonton) the expert.

KASSPr assesses the strength and union of synoptic features that are known to influence the formation of thunderstorms. The rule base is divided into a set of NECESSARY, SUFFICIENT and MODIFYING conditions. For there to be severe weather, a set of eight NECESSARY conditions must all be met. The rules reflect influences that would dampen severe convection such as the presence of an upstream 500 mb thermal ridge or 850-500 mb thickness ridge.

If any NECESSARY condition is not met, no severe weather is forecast. If all are met, one of two SUFFICIENT conditions must be met. These rules estimate the forecast storm environment, requiring a favourable combination of upper and lower jet streams, low level convergence zones and areas of positive vorticity advection.

If all NECESSARY conditions and at least one SUFFICIENT condition are met, severe weather is forecast for that location at some unspecified time later in the day. A 50% probability of occurrence is assigned as is maximum expected hail size of 25 mm. The remainder, and bulk, of the rules are MODIFYING conditions that adjust this probability and hail size.

All MODIFYING rules have been tested to ensure the results are independent of the order of rule firing.

KASSPr uses as input fields derived from an operational NWP model, and convective index information. Currently, KASSPr only uses the T+12 forecast data valid at 00Z (6:00 PM MDT). It is assumed that this single time is of the entire convective period.

The NWP forecast fields are contoured and displayed to the forecaster. He has the ability to interactively modify any of the fields based on information he may have at hand (e.g. satellite photos, local knowledge of model behaviour etc.). The forecaster must also add analyzed features such as the location of jet, vorticity troughs and ridges, areas of positive vorticity advection, thickness ridges etc.

Once these modifications and analyses are complete the forecaster invokes a sampling program that abstracts values for a pre-defined number of points within a grid. Once the sampling program is complete, the expert system is invoked for each site and a severity index related to maximum expected hail size and probability of occurrence is obtained (Appendix 1).

KASSPr was written in OPS5 and runs on a variety of DEC VAX equipment.

TEST PERIOD

SWIFT was implemented and operated at the Alberta Weather Center during the summers of 1988 (late July-August) and 1989 (June-August) in parallel with the operational severe weather forecaster. KASSPr was implemented in 1989 (July-August).

TEST SCENARIO

SWIFT was operated by a summer student for both periods. Special datasets from Operational Finite-Element model runs at the Canadian Meteorological Center were retrieved via modem each morning, pre-processed on an HP 9000 Engineering workstation and combined with local hourly weather report data. This data was ingested into the SWIFT system and the expert system was run. The results were displayed on the Xerox 1186 Workstation and manually saved for later.

KASSPr was either run by the summer student or the expert (J. Bullas). Required fields were once again provided by the Finite-Element model and the Graphics Editor on an HP9000 workstation was used to input the 00Z field forecasts. An EGDEX (Checkwitch) was entered into the system manually in gridpoint form. The Sampler results were sent via modem to a VAX 750 in Downsview where the expert system resided. Results in tabular form were returned to the center to be saved for later verification.

RESULTS

Lessons learned

The following lessons were learned as a direct result of the experiment:

i) In order to be used operationally, results must be available in a timely fashion, otherwise the effectiveness of the systems is sharply reduced. Data communications was the single largest factor which the timeliness of the forecasts in our experiment.

ii) Results must be interpretable in terms of what the forecaster currently understands about the knowledge-based system itself and the current weather analysis.

iii) The methodology used must be understood and accepted by the forecaster the guidance to be accepted and understood. It was necessary for the human expert to be present and explain the results of SWIFT in order for the to be accepted by the operational forecasters, as the SWIFT technique is not known or understood. The most common question was "OK, but does this mean?". Kasspr, on the other hand attempts to emulate what the techniques the forecaster is already using.

iv) Once the expert system has one or two notable successes, the guidance provided cannot be ignored by the operational forecasters. Despite the overall skill level relative to the forecaster, the forecast will either provide confidence if it agrees with the existing school of thought or challenge the analysis if it does not. Both consequences appear to be salutary.

vi) A number of implementation problems were discovered in KASSPr which reduced its skill level during the experiment. This was not surprising considering the hasty implementation and prototype status. For example, the simplifying assumption that one time (00Z) is representative of the entire daily convective period was known to be flawed. In fact, late breaking convection (after 00Z) can be the most severe and may understandably be flagged as a nil event by KASSPr.

vii) Data communications remained the one major problem reducing the utility of KASSPr in an operational environment.

viii) The interactive graphical display of synoptic-scale weather information appears to be well accepted.

ix) From early experience with KASSPr it appears several modifications will be required. Paramount is the need for time interpolation. The forecaster will have to put in at least two sets of synoptic scale features, but this will allow a forecast of the time of convective activity and more importantly KASSPr will not miss potentially severe events happening late in the day. Rules will also have to be added to KASSPr to capture the intermediate "significant") weather events.

Verification results (1989)

The results of convective outlooks produced by SWIFT, KASSPr and the Alberta Weather Center were compiled and verified against the same data using the identical, standard methodology employed by the Alberta Weather Center. The verification was conducted by the Alberta Weather Center severe weather program supervisor (G. Vickers). Contingency tables were developed and the "standard" rare-event statistics derived, namely:

Probability of Detection (POD)
-the fraction of actual severe weather events which were properly forecast. Ideal score 1.0.

False-Alarm Ratio (FAR)
-the fraction of forecasts of severe weather which did not verify. Ideal score 0.0.

Critical Success Index.
-an index combining the above which is maximized by a high POD and low FAR. Ideal score 1.0.

Heidke Skill Score.
-fractional increase in skill over chance. Ideal score 1.0

Table 1. shows the results of the verification.

Discussion of verification results

The raw results must be put into perspective. It is a very difficult task to forecast mesoscale weather precisely in terms of time and space, some 9-15 hours after data (analysis) time. Outlooks issued in the morning therefore almost always show much lower skill than watches and warnings issued later in the day with updated information. The absolute magnitude of the scores are also dependent upon the exact methodology employed. For example, the larger the individual areas verified, the more the storm-scale interactions are averaged out, and the better the overall verification of a forecast based on synoptic-scale information. What is important and significant for this experiment is the comparative results, as follows:

i) SWIFT had comparable skill to the human forecaster during the experiment over its domain.

ii) KASSPr, despite numerous implementation problems and compromises made in order to implement the system by last summer, exhibited more skill than the operational forecaster.

PRESENT STATUS

Following this experiment and another one - Shootout '89, (McLeod et al), a number of modifications have been made to KASSPr. Most important from an operational perspective is that the expert now resides on the same system that the graphics editor resides, re-programmed in OPS '83. There is therefore no requirement to transfer the results of the sampling to another host to generate the forecast, a process which consumed 30-45 minutes during this test. Of equal importance is that there are now a set of rules for moderate thunderstorms developed by Bullas and de Lorenzis. Several minor implementation problems have also been corrected.

The modified KASSPr system is now undergoing testing and tuning using the Alberta and Boulder data. This will hopefully increase the skill level even farther.

FUTURE PLANS

It is planned to conduct an expanded experiment in the summer of 1990 at the A.E.S. Alberta and Prairie Weather Centers in Edmonton and Winnipeg respectively. It is planned to use KASSPr in operations and have the forecasts ready in time to be used as input to the operational severe weather forecast products.

It is also planned to compete with other systems in another comparative experiment similar to Shootout '89 in 1990. Details of this expanded intercomparison experiment had not been finalized at time of writing.

CONCLUSIONS

The skill levels of prototype knowledge-based systems developed in Canada for severe weather forecasting are apparently approaching a useful level. Even if no more skillfull than the human forecaster (and there is evidence they may be), they appear to offer a valuable second opinion to confirm or challenge the prevailing diagnosis. The outputs should also be useful as a first "guess" in panic situations. These latter two hypotheses will be further tested during the upcoming trials in Edmonton and Winnipeg.

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Table 1.

1989 SEVERE WEATHER VERIFICATION (ALWC SWIFT KASSPr)

	JULY			AUGUST			SEASON		
	AL	SW	KA	AL	SW	KA	AL	SW	KA
Days	11	09	11	17	17	17	28	26	28
POD	0.33	0.33	0.58	0.41	0.06	0.41	0.38	0.15	0.48
FAR	0.84	0.70	0.59	0.80	0.92	0.81	0.82	0.82	0.74
CSI	0.12	0.19	0.32	0.16	0.04	0.15	0.14	0.09	0.20
HSS	0.14	0.27	0.44	0.21	0.02	0.19	0.18	0.12	0.28
%CO	84	92	92	87	91	86	86	91	88
PA(Y)	0.16	0.30	0.41	0.20	0.08	0.19	0.18	0.18	0.26
PA(N)	0.95	0.96	0.97	0.96	0.94	0.96	0.96	0.95	0.96
BI(Y)	2.08	1.11	1.42	2.06	0.71	2.18	2.07	0.85	1.86
BI(N)	0.93	0.99	0.97	0.93	1.02	0.93	0.9	1.01	0.94

Days= No. of forecast days; AL= ALWC Forecasts; SW= SWIFT Forecasts; KA= KASSPr Forecasts; %CO = % Correct

Appendix 1. Sample KASSPR output for Alberta - August 14, 1989

Location	Time	Severity	Probability
FORTNELSON	22700	0.0	0.0
HIGHLEVEL	22700	0.0	0.0
WOODBUFFALO	22700	0.0	0.0
FORTSTJOHN	22700	25.0	95.541
GRANDEPRAIRE	22700	30.32360	92.03751
SLAVELAKE	22700	34.26339	74.40625
FORTMCMURRAY	22700	0.0	0.0
EDSON	22700	37.22447	90.9
EDMONTON	22700	26.31130	74.92058
STPAUL	22700	16.11111	71.875
REDDEER	22700	29.49219	91.00572
CALGARY	22700	25.0	92.2
CORONATION	22700	0.0	0.0
LETHBRIDGE	22700	30.10742	92.2
MEDICINEHAT	22700	0.0	0.0
BANFF	22700	25.0	93.175
JASPER	22700	25.0	92.53516

STRATUS: A PROTOTYPE EXPERT ADVISOR FOR FT'S

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ABSTRACT

Ongoing work in the development of an expert advisory system for aviation terminal forecasting is described. A preliminary verification of a demonstration protoype (OASIS) that applied a set of rulebased on physical reasoning to model output has shown that the rules need some modification and that direct numerical model output of some of the parameters cannot be used without developing a module that adapts the output to the requirements of the expert system. Examples of the validation of the system will be presented.

RÉSUMÉ

L'état du travail sur le développement d'un système expert conseil pour la prévision aéronautique des aérogares est décrit. Une vérification préliminaire d'un prototype de démonstration (OASIS), qui applique des règles basées sur la physique aux sorties brutes d'un modèle numérique, a démontré que les règles doivent être modifiées et que les sorties du modèle ne peuvent pas servir sans le développement d'un module qui adapte les sorties aux besoins du sytème expert. Des exemples de la validation seront présentées.

1. Introduction

The complexity of the weather forecasting process is well known. There are numerous sources of data from a number of different computer systems. This data varies both in quality and quantity and consists of not only observations that are either quantitative (temperature, pressure, humidity, etc.) or qualitative in nature (cloud type, satellite cloud patterns, radar echos of precipitation, etc.) but also includes a large number of analyses and forecasts of various meteorological fields. To this data, the forecasting team is expected to apply complex physical laws as well as empirically derived rules and produce a number of different types of forecasts that include estimates, either qualitatively or quantitatively, of reliability. Since the importance of the various physical processes varies according to the geographical location, forecasters tend to develop, through experience, local expertise that is very difficult to transfer from one place to another.

Because of the constraint of time and the complexity of the physical processes and data, forecasters rarely use analytical reasoning based on their university and professional training to arrive at the best possible forecast. Instead forecasters tend to use the same approach as that of ex-

perts in other fields that work with similar constraints; i.e., the experienced forecaster, using a personal choice of parameters among those available, rapidly categorizes or prototypes the meteorological situation according to his experience and generates a sequence of weather events that correspond this prototype. If enough other data or the unfolding weather contradict this first scenario, the forecaster will choose a different prototype from his experience which will imply a new forecast. This approach to decision making has been named Recognition Primed Decision by Klein, et al (1986) and Klein (1987).

In order to improve on the current situation in weather forecasting, a prototype expert advisory system for producing FT's is being developed at the Centre de recherche informatique de Montréal in collaboration with the Meteorology group at the Université du Québec à Montréal, the School of Computing Sciences at McGill University, the Atmospheric Environment Service, and Météoglobe Canada Inc. The goal of the system is to combine (deep) knowledge of the physics of meteorological phenomena with the mostly empirical (shallow) knowledge gained by weather forecasters through their of experience with many weather situations. On the poster, the progress toward developing the prototype FT expert advisory system will be presented.

2. Previous work: SCAPIN and OASIS

A previous prototype called OASIS, already reported on by Zwack, et. al. (1989), forecasts realistically (not necessarily accurately) the low cloud portion of an FT by combining observations, numerical model output as well as empirical forecasting rules using a structure based on physical principles. It was designed to show the feasibility of such a system and used standard level numerical model data at six hour intervals of temperature, humidity, vertical motion, and surface winds from the Canadian Operational Finite Element model (Staniforth and Daley, 1979). Intermediate values were interpolated linearly. The system was initialized for Montreal's Dorval Airport by using the most recent numerical model output for the initial time..

The system was structured around a qualitative model of the atmosphere that represents the physical processes responsible for clouds at a particular location. This model, choice of data, and rules were developed through a collaborative effort between operational and theoretical meteorologists. A group of weather forecaster trainers, weather forecasters and synoptic meteorologists (called domain experts) brainstormed the various scenarios and identified the physical processes that produce low clouds. This knowledge was then structured and programmed with the help of computer scientists (knowledge engineers) (Cotnoir and Zwack, 1988).

3. Progress with Stratus

The importance of validation and revision in the development of expert systems is well known (Zubrick,1988). In the early phases of STRATUS, the rules used by OASIS are being validated with the goal of making improvements. Preliminary results from manual validation using the best possible estimates from observations of the required parameters indicate that some mostly minor modificaions of the rules will likely be required (Desmarais et. al., 1990). This validation procedure is being automated so that the revisions reflect the results of a large set of cases.

The second problem that is being attacked is that of developing the best ways of forecasting the parameters that are used in the rules of for the diagnosis of low clouds. In OASIS, numerical model output such as temperature, dew point, turbulence, boundary layer height, surface wind, and vertical velocity were used in the hope that the models may provide good sources of these parameters. Preliminary checks of the precision of model forecasts at three hourly intervals indicate that although the numerical model forecasts of the surface pressure field were quite good:

1) the vertical motion during the first three hours was contaminated by a "spin-up" problem;

2) after three hours there seemed to be some rather weak noise in the vertical motion field of the order of 10^{-1} Pa s^{-1} (1 μbar $s^{-1} \approx 1$ cm s^{-1});

3) the temperature and dew point profiles were too cold and sometimes well forecast and sometimes poorly forecast;

4) the boundary layer height and turbulent energy fields were extremely noisy;

5) the surface wind sometimes had spikes in the magnitude.

These results suggest that these parameters cannot be used directly in STRATUS but that rules must be developed to make the model output suitable for forecasting low cloud and that probably other sources of the parameters must be found. Presently work is ongoing in extracting techniques for forecasting these parameters from an expert forecaster. Preliminary results will be described.

4. Acknowledgements

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THE FORECAST PRODUCTION ASSISTANT

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Abstract

The paper describes a system developed to assist the operational forecaster in the production of worded forecasts. The Forecast Production Assistant (FPA) has been under development for the past four years and has recently undergone operational testing in three Canadian weather centres. The system is currently limited to producing marine forecasts for these three weather centres but expansion in many areas is planned. The paper lists the system's modules and describes their basic functioning.

Résumé

Cet article décrit un système qui a pour but d'aider le prévisionniste opérationnel durant la préparation des prévisions écrites. Cet "Assistant-Prévisionniste" a été en dévelopement durant les quatres dernières années et fut récemment mis à l'épreuve dans trois centres de prévisions au Canada. Présentement, le système prépare uniquement les prévisions maritimes pour ces trois centres météorologiques mais un élargissement de ces fonctions est prévus. Cet article donne une liste des différents modules du système et décrit leur fonctionnement.

I N T R O D U C T I O N

As with many other national meteorological services, Canada's Atmospheric Environment Service is in the process of developing workstations for the use of operational meteorologists. In this case, the workstation is being developed largely in-house and by various R&D units. One component of the eventual workstation is the Forecast Production Assistant (FPA). The FPA is in itself a complex computer system that will eventually significantly change the way an operational meteorologist performs his daily duties. It has been under development in the Atmospheric Environment Service since 1986, with intensive efforts beginning in 1988.

P U R P O S E / S E T T I N G

In its eventual form, the Forecast Production Assistant will be used by operational meteorologists in all nine weather centres in Canada. The system will allow weather forecasters to draw a time series of detailed weather depiction forecasts and to automatically produce a variety of worded weather forecasts. Using modern text generation software (Goldberg 1988) these forecasts can be developed for a wide range of forecast users, e.g. the general public, the aviation community, the marine community, forestry, ground transportation etc. In addition these forecasts can be tuned to take advantage of local preferences in vocabulary and syntax. As the majority of the text generation process is not language specific, it is relatively economical to implement text generation in both of Canada's official languages, thus avoiding costly and occasionally sub-optimal translation.

It is apparent from early tests that the graphical depictions themselves can form the basis of a set of graphical products which would go directly to various user groups.

The current version of the FPA (Version 1.0) is limited to producing marine forecasts for three Canadian Weather Centres, the Newfoundland Weather Centre, The Maritimes Weather Centre and the Ontario Weather Centre. The forecasts are produced in French and English

The FPA is implemented on the Hewlett-Packard 9000 computer system. The interactive portions of the system are written in C and use HP's Starbase graphics package. The user interface is built using NorthWest Digital's XUI product. The linguistic generation software is written in Quintus Prolog.

S Y S T E M D E S C R I P T I O N

The system is composed of five modules, each of which will be described in general terms:

- Communications
- Guidance Analysis
- Depiction Editor
- Time Linker
- Language Generator

Communications Module

The FPA uses the latest Numerical Weather Prediction (NWP) forecasts as a guidance for the forecaster. The NWP model of preference is the Canadian Regional Finite Element (RFE) model.

The communications module on the FPA queries the local database for newly arrived data and retrieves them when available. All data are time stamped with year, Julian day and valid time. Forecast issue times are stored internally to the file.

At present, the T+0, T+12 and T+24 hour forecasts are available to the FPA by 1415Z, the T+36 and T+48 hour forecasts are available by 1500Z.

Guidance Analysis Module

Once the forecaster is notified of the receipt of new NWP guidance, he may begin the process of guidance analysis. He must first select a forecast time to work on, and is the presented with a list of available guidance products. Products are defined as a combination of a number (usually 2) of fields at the same level and time. For example 700 mb height and temperature fields are combined into one product.

The forecaster has the ability to manipulate guidance products in several ways. As they are all represented as continuous B-spline surfaces (Trafford, 1990) the individual fields can be sampled at any point. To ease readability, the color and line style of any field can be rapidly changed. Finally the forecaster can annotate the guidance field in any manner he sees fit to assist him in drawing his weather depiction prognosis. He is permitted a wide variety of colors and line styles so that annotations on various products can be viewed simultaneously.

Depiction Editor Module

Once the forecaster has reviewed and annotated guidance he begins work on the weather depiction chart for a given projection time. As noted above, the guidance products and/or the annotation fields may be present "under" his depiction chart. In practice forecasters usually carry only the annotation fields to the depiction creation stage.

The forecaster must create or accept four or five forecast elements for each marine weather depiction chart. These elements are:

- MSL pressure
- Surface temperature
- Clouds and weather
- Wind deviation from geostrophic
- Wave heights (some offices)

He may choose to first work on one time for all elements or, more commonly, work on one element for all times.

The Depiction editor module allows him to examine, modify and/or create these fields as he sees fit. Regardless of field type, he is allowed to Sample and Label the fields as he sees fit. In the case of surface MSL pressure fields a tool is provided that samples the first derivative of the field and produces geostrophic wind barbs at selected points. The Modify features are, however, different for continuous (pressure, temperature, wave heights) or discrete (clouds, weather, wind deviation from geostrophic) fields.

Linguistics Processes Module

The process of generating text is actually composed of several identifiable, sequential steps:

- Graphics sampler
- Time merge
- Space merge
- Text generation

Graphics Sampler

All public forecasts (including marine) are divided into regions. A typical marine forecast will have 10 to 20 regions. The first step in generating a regional forecast is to sample the depiction charts at the appropriate locations. For our purposes, we have determined, by the examination of historical text, the finest areal breakdown possible for each forecast region. This does not appear to be a constant, i.e. some regions are never split while others may be split into as many as three parts if the forecast so warrants. Sample points are therefore defined as the centroid of regions or possible sub-regions.

Time Merge

Once the time series of weather elements are available for a region or sub-region, a Prolog program examines each one for 'significant' changes. This step is clearly necessary to limit the number of part periods required in a given regional forecast.

Space Merge

Once strings of weather composed only of significant element changes for each region have been created, the next step is to attempt to group regions. This step is needed to limit the overall length of forecast bulletins.

Text Generation

The actual text generation is the final step and the ultimate goal in the FPA system. The process of developing the software begins with the analysis of human written text. In our case over one million words of text were analyzed covering all seasons and hopefully adequately covering all meteorological situations. Meteorologists then worked with linguistic specialists to explain why certain phrases were used in some situations and not others. This process is again expensive and time consuming, and somewhat endless. It does however result in text that is essentially indistinguishable from that produced by humans; it has a richness and variation that cannot be accomplished by simpler techniques.

Fully two-thirds of the text generation process is in developing concepts and in planning and is independent of target language. Therefore, this system was easily modified to produce French as well as English text, a requirement for all Canadian weather forecasts. Further details on the text generation module can be found in (Goldberg, 1988).

T I M E L I N E S S

One of the original questions about the FPA concept was how long it would take to generate forecasts.

The process of examining guidance and preparing a time series of weather depiction charts is time consuming, but is the basic function of a forecaster in a major weather centre. To prepare well considered, accurate depictions to T+48 requires at least two hours of fairly intensive effort. Most, if not all, meteorologists who have tried

this system however, find it immensely rewarding work and more demanding and reflective of the scientific training they have undertaken to become a meteorologist.

The process of time linking and interpolating the elements to 3-hour intervals requires about 15 minutes. This time needs to be reduced in later versions.

Sampling can be a surprisingly time consuming process. The process takes up to 5 minutes on our current hardware.

Time and space merging are extremely quick procedures.

The time required for text generation, including conceptualization, planning and two-language realization is highly variable. It depends on the complexity of the meteorological situation and the number of groups of regions. Typically, a large forecast (19 regions) in a moderately complex situation will require 6 to 10 minutes to generate. This time appears to be acceptable to operations for scheduled forecasts but needs to be reduced in amendment/warning issuance situations.

F U T U R E D E V E L O P M E N T

Over the next few years the development plan for the FPA includes the following items: extension to other forecast types, beginning with inland public forecasts for southern B.C.; geographical extension to other weather centre areas of responsibility in Canada; investigation of utilizing weather depiction charts as products.

C O N C L U S I O N S

Over the past four years the Atmospheric Environment Service has developed Version 1.0 of the Forecast Production Assistant. Early reviews of the system by operational meteorologists in off-line testing have, in spite of implementation bugs, been favourable. The extension of this system into the production of a wide range of operational products is assured.

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A STATISTICAL WEATHER ELEMENT FORECAST SYSTEM WITH AUTO-CORRECTION ERROR FEEDBACK.

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RESUME.

A forecasting system with auto-correction, called SPOC, has been developed and applied to forecasts of total cloul opacity and probability of precipitation over six and twelve hours produced using the "Perfect Prog" (PP) approach. The SPOC system uses the data compiled in the previous 90 days to calculate the corrections to be applied to the original PP forecasts

The frequency distribution of SPOC forecasts of total cloud opacity conforms completely to that observed. Moreover, the skill of the forecasts is considerably improved in comparison with that of the original PP forecasts. In addition, SPOC forecasts of probability of precipitation are clearlyu superior to the original PP forecasts.

The main purpose of the SPOC system is to make PP forecasts immune to systematic errors in the driving model, while conserving their independence from that driving model. The SPOC system is self-su7fficient, and makes it possible to give the PP technique all the benefits, and none of the drawbacks, of the Model Output Statistics (MOS) approach.

Un système de prévision avec auto-correction (SPOC) a été développé, et appliqué sur les prévisions de l'opacité totale des nuages et des probabilités de précipitations sur sux et sur douze heures daites à partir de l'approche "prévision parfaite" (PP). Le système SPOC utilise les données accumulées sur les derniers 90 jours pour calculer des corrections à appliquer sur les prévisions PP originales.

Les prévisions SPOC de l'opacité totale des nuages ont une distribution de fréquence tout à fait conforme à celle observée. L'habileté des prévisions est aussi considérablement améliorée par rapport à celle des prévisions PP originales. Les prévisions SPOC de probabilité de précipitations sont aussi nettement supérieures aux prévisions PP originales.

La principale raison d'être du système SPOC se résume dans le fait que les prévisions PP deviennent ainsi insensibles aux erreurs systématiques du modèle moteur, tout en conservant leur indépendance vis-à-vis ce même modèle moteur. Le système SPOC est auto-suffisant et permet de donner à la technique PP, tous les avantages de l'approche "Model Output Statistics" (MOS), sans en y introduire les lacunes.

1.0 INTRODUCTION.

The Canadian Meteorological Centre (CMC) developed a statistical forecasting system based on the "Perfect Prog" (PP) approach (Klein et ..., 1959) to predict total cloud opacity at three-hour intervals, probability of precipitation amounts of 0.2 mm or more (water equivalent) at six-hour intervals (POP06), probability of precipitation amounts of 0.2, 2.0 and 10.0 mm or more at

twelve-hour intervals (POP12) (Verret, 1987), and spot time temperatures at three-hour intervals (Brunet, 1987). PP forecasts are prepared for 264 Canadian stations, out to 144 hours in the 00 UTC production cycle, and out to 72 hours in the 12 UTC cycle.

The CMC also has a statistical forecasting system based on the "Model Output Statistics" (MOS) approach (Glahn and Lowry, 1972), which predicts total cloud amount at three-hour intervals (Verret, 1984; 1985; 1986), POP06 and POP12 (Yacowar et al, 1985), and spot temperatures at three-hour intervals (Brunet, 1986). The entire MOS system was described by Brunet, Verret and Yacowar (1986). MOS forecasts are prepared for 264 Canadian stations out to 72 hours in both the 00 and the 12 UTC production cycles.

The performance of the PP and MOS statistical forecasting systems were compared by Brunet, Verret and Yacowar (1987; 1988), using the forecasts produced at 134 Canadian stations during the 12 months of 1986 as an independent sample. The study showed that PP forecasts of sky cover were superior to the MOS forecasts. PP forecasts of probability of precipitation were better than MOS forecasts in the short term (36 hours or less), after which MOS forecasts took the lead, mainly because of their greater reliability. PP forecasts were found to be sharper than MOS forecasts at all forecast intervals for all predictands.

The MOS technique has the advantage of implicitly taking account of systematic errors in the driving model (Verret, 1987). Thus the MOS approach is tied to the driving model, and the MOS regression equations become obsolete whenever a major change is made to that driving model (Carter, 1986; 1987). The PP technique is independent of the driving model, but cannot take account of its systematic errors. Both of the numerical models available at the CMC, i. e. the Regional Finite Element model (CDNEFR) (Staniforth and Daley, 1979; Benoit et al, 1989), and the Spectral model (CDNSPE) (Daley et al, 1976), have systematic errors, like most numerical models, which result in a drift in the models' climatology (Verret, 1988b). Both Canadian models have the same tendency to lower geopotential heights and to lower temperatures, during their integration. This is accompanied by a clear increase in the specific humidity. The models' drift is reflected in the statistical forecasts based on the PP approach (Verret, 1988b), but not in the MOS forecasts (Verret, 1987).

Following encouraging experiments at the CMC on post-processing systems for statistical forecasts of weather elements in an effort to improve performances (Verret, 1988a; Brunet, 1988; Yacowar, 1987), a system was developed in which PP forecasts could be made immune to the systematic errors of the driving models. This statistical forecasting system with auto-correction (SPOC), described below, is applied only to the PP forecasts. It is self-sufficient, and makes it possible to combine in one system the MOS immunity to systematic errors in the driving model, and the PP independence of that driving model.

2.0 THE SPOC SYSTEM.

The driving model used to produce PP statistical forecasts is the CDNSPE model. The mean error in probability of precipitation forecasts caused by the model's drift can easily be corrected by calculating the short-term climatology of the observations and the climatology of the forecasts over the same period. The difference between them gives the correction to be applied to the forecasts. A period covering the 90 previous days has been selected for calculating the difference in climatology, in real time.

The problem is somewhat more complex where forecasts of total cloud opacity are concerned, since linear regression makes it impossible to reproduce the characteristic U-shaped frequency distribution of observed total opacity (Verret, 1985). The cumulative frequency distributions of PP forecasts and of observations of total cloud opacity are shown in figure 1. The frequency distribution can be reproduced from the derivative (or slope) of the cumulative frequency

distribution. The characteristic U-shape is present in the observations, but the frequency distribution of the forecasts is inverted in comparison to that of the observations.

The forecasts are forced to conform to the frequency distribution of the observations by projecting the cumulative frequency distribution of the observations onto the cumulative frequency distribution of the forecasts. This makes it possible to determine the corresponding forecast threshold values, on the X-axis, with the proper cumulative frequency. These threshold values are then used to correct the forecasts. For example, in figure 1, the cumulative frequencies observed of 2 and 3 tenths are 27.58% and 34.13% respectively. For the forecasts to show the same cumulative frequencies, all the forecasts between 4.34 tenths and 4.88 tenths are assigned the value 3 tenths. The threshold values are calculated by linear interpolation between the forecast cumulative frequencies, using the same 90-day period as for the probability of precipitation.

In figure 1, the ten forecast threshold values calculated are, respectively, 2.54, 3,59, 4.34, 4.88, 5.34, 5.74, 6.09, 6.57, 7.15 and 7.99 tenths. All the forecast values of 2.54 tenths or less take a value of zero. All of the forecast values between 2.54 and 3.59 take the value 1 tenth, and so on. Finally, all the forecast values of more than 7.99 take the value 10 tenths. This approach makes it possible to force the forecast values to conform to the frequency distribution of the observation, and to correct for the model's drift.

All the corrections applied, both to forecasts of total cloud opacity and to POP06 and POP12 forecasts (threshold values of 0.2, 2.0 and 10 mm), are calculated independently at each station and for each forecast projection, and are continually updated at each production cycle. If more than half the observations are missing at a given station over the previous 90 days, the frequency distributions of total cloud opacity and frequencies of precipitation at those stations are calculated from the values available from surrounding stations, using weights that are inversely proportional to the distance between the target station and the surrounding stations. Forecasts are always available, however, and the lack of data causes no problem with regard to the calculation of forecast frequencies.

The 90-day period used to calculate the corrections is sufficiently long for the frequency distribution of sky cover and of precipitation, observed and forecast, to be representative. However, it imparts a certain inertia to the SPOC system, particularly if there is a abrupt change in weather regime.

3.0 RESULTS.

3.1 OPACITY.

SPOC forecasts of total cloud opacity produced at 00 UTC during the period from October 1, 1988 to March 31, 1989 (six months, winter season), were compared with the original PP forecasts, for 173 Canadian stations. The results are summarized in figure 2.

The upper graph in figure 2 shows the ratio between the number of cases forecast and the number of cases observed, for each tenth of opacity, at 36 hours, for the SPOC forecasts and the original PP forecasts. If the frequency distribution conforms to that observed, the curve should be flat with a value near 1. The frequency distribution of the SPOC forecasts is a perfect reproduction of the observed frequency distribution (characteristic U-shape), despite a slight overestimation of the number of forecasts near 10 tenths and a marginal underestimation of the number of forecasts near zero tenths. The frequency distribution of the original PP forecasts is far away from reality.

The lower left-hand graph in figure 2 shows the Heidke skill score (Heidke, 1926) calculated from three by three contingency tables, with categories 0-3, 4-6 and 7-10 tenths. The SPOC forecasts are clearly superior to the original PP forecasts, up to 144 hours. The Heidke skill score of the SPOC forecasts is equal or greater than 0.4 up to 36 hours, as compared with only 12 hours for the original PP forecasts.

The lower right-hand graph in figure 2 shows the mean error in forecasts of total cloud opacity for the SPOC system and the original PP system. The original PP forecasts have a mean error that grows with the forecast projection, reflecting the drift in the driving model (Verret, 1988b). This drift in the forecasts is controlled by the SPOC system, and its mean forecast error remains stable near 0.5 tenths, up to 144 hours.

3.2 POP06.

SPOC forecasts of probability of precipitation over six-hour periods were compared with the original PP forecasts over the same period and at the same stations as in section 3.1, The results are shown in figure 3.

The two system's skill levels as measured with the Brier score (Brier 1950), with respect to climatology, are very similar in the short term. However, the SPOC system improves upon the original PP forecasts more and more as the forecast projection increases. The SPOC forecasts have skill with respect to climatology up to 84 hours, as compared to 72 hours for the original PP forecasts, i. e. a gain of 12 hours obtained simply be deducting the mean error of the forecasts.

The mean error of the SPOC forecasts is very stable at about 1.5%, up to 144 hours, suggesting that the SPOC system effectively controls the drift in the driving model.

The SPOC system produces a clear improvement in the reliability of probability of precipitation forecasts over six hours. The frequency distribution of the forecasts is also improved, with a considerable increase (more than 5%) in the number of cases near 0%, and a decrease in the number of cases forecast close to climatology. The number of cases forecast near 100% decreases by about 1%, but the overall sharpness of the forecasts is improved.

3.3 POP12 (0.2 mm threshold value).

SPOC forecasts of probability of precipitation over 12-hour periods (threshold value of 0.2 mm) were compared with the original PP forecasts, as in section 3.2. The results are shown in figure 4.

The two forecasting systems have very similar levels of skill, although the SPOC system comes out slightly ahead. The mean error in the SPOC forecasts is very stable at about 4%, while the mean error in the original PP forecasts reflects the drift in the driving model.

SPOC forecasts are marginally more reliable than the original PP forecasts. The frequency distribution of the two forecasting systems are similar, except near the extremes. The SPOC system shows an increase of about 2% in the number of cases forecast near 0%, and a decrease of about 1% in the number of cases near 100%.

4.0 CONCLUSIONS.

The SPOC system, despite its simplicity and ease of application, results in a clear improvement upon the original PP forecasts of total cloud opacity and of probability of precipitation over six-hour periods and marginal improvement in the probability of precipitation over twelve-hour periods. The most notable advantage of the SPOC system relates to its forecasts

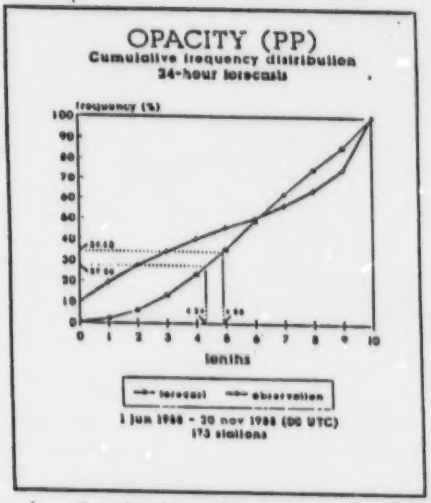

Figure 1: Cumulative frequency distribution of PP forecasts and observations of total cloud opacity. The forecasts at 173 Canadian stations produced during the period from June 1, 1988 to November 20, 1988, 00 UTC cycle, and the observations at those same stations, were used. The dotted lines represent a projection of the cumulative frequency distribution of the observations onto the cumulative frequency distribution of the forecasts.

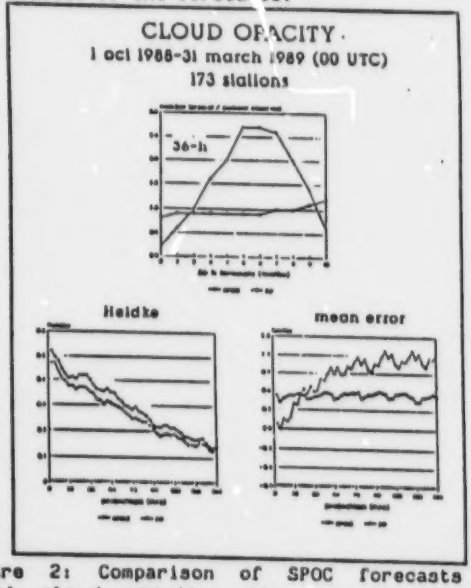

Figure 2: Comparison of SPOC forecasts of total cloud opacity with the original PP forecasts. The independent sample is made up of forecasts prepared at 173 Canadian stations in the 00 UTC cycle, over the period from October 1, 1988 to March 31, 1989. The upper graph shows the ratio between the number of cases forecast and the number of cases observed, for each tenth of total cloud opacity. The lower left-hand graph shows the Heidke skill score, calculated from 3X3 contingency tables. The lower right-hand graph shows the mean forecast error.

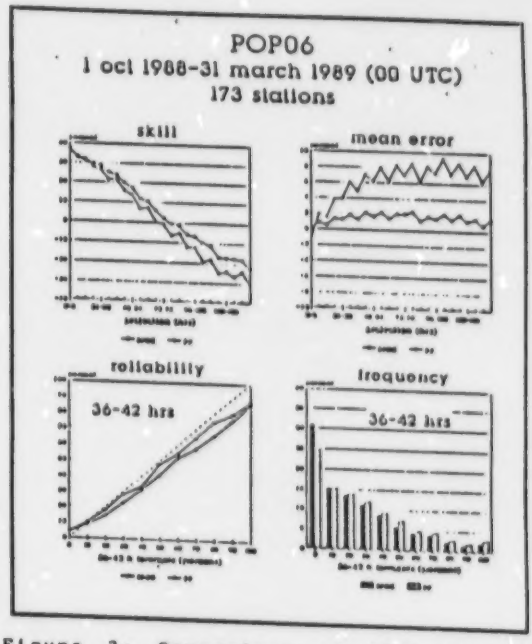

Figure 3: Comparison of SPOC six-hour forecasts of probability of precipitation with the original PP forecasts. The independent sample is the same as in Figure 2. The upper left-hand graph shows the Brier score with respect to climatology. The upper right-hand graph gives the mean forecast error. The lower left-hand graph shows the reliability of the forecasts, and the lower right-hand graph gives the frequency distribution of the forecasts.

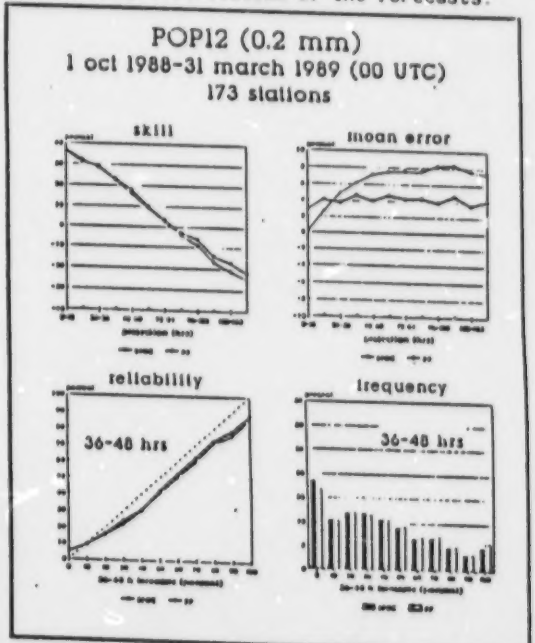

Figure 4: Same as in Figure 3 except for the twelve-hour forecasts of probability of precipitation (threshold value of 0.2 mm).

of total cloud opacity; the SPOC system forces the forecasts to conform to the characteristic U-shaped frequency distribution of the observations almost exactly.

Another important advantage of the SPOC system is the fact that PP forecasts no longer reflect the drift in the driving model; at the same time, they remain independent of the driving model. Thus the SPOC system makes it possible to give the PP technique most of the attributes of the MOS approach.

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A CONCEPTUAL MODEL OF SEVERE CONVECTIVE OUTBREAKS IN ALBERTA

by

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Abstract: An analysis of observational data gathered during a mesoscale field experiment in central Alberta (LIMEX-85) has led to a conceptual model of severe convective outbreaks in Alberta. It is proposed that the most intense convective events result when upper-level cooling, associated with an advancing trough, occurs in phase with strong surface heating over the Alberta foothills. The deep destabilization, localized over the elevated foothills, acts to amplify the normal mountain-plain circulation and permits moist plains air to reach the convectively active foothills through underrunning of the capping lid.

Résumé: Les analyses des observations provenant d'une expérience sur le terrain (LIMEX-85) nous ont menes à formuler un modèle de la convection sévère en Alberta. On suggère que les orages les plus violents se déclenchent lorsq'un refroidissement en altitude, associé à un creux à l'échelle synoptique, s'effectue pendant la période de réchauffement maximale au sol des contreforts des montagnes Rocheuses. Une telle déstabilisation permet l'amplification de la circulation montagne-plaine ce qui a pour conséquence le transport de l'air humide des plaines vers les contreforts ou les orages se développent.

Introduction

Central Alberta has long been known as a region highly susceptible to severe summertime convection (Fig. 1). Climatological statistics show that the area is affected by hail on an average of 61 days each summer. Between 10 to 20 tornadoes are reported annually in the province. Although most of the hail which falls is the result of relatively weak single and multicell storms, highly organized convection (multi or supercell storms) develops four to five times a summer and produces widespread, large hail and/or tornadoes. In particular, the Edmonton tornado event of July 31, 1987 demonstrated quite dramatically just how vulnerable the increasing population of the region is to these organized outbreaks of severe convection. The extensive property damage and loss of life resulting from this tornado underscored the need for improved forecasting, public awareness, and warning dissemination of such events.

On days with severe convection in central Alberta, the morning soundings generally show a lower-tropospheric inversion or capping lid which initially inhibits the formation of deep convection. Towering cumulus clouds first form over the foothills region in the early afternoon. These clouds intensify

rapidly into cumulonimbi which move eastward often in the form of a squall line. By late evening the developing storms move into Saskatchewan where they sometimes evolve into mesoscale convective systems whose areal extent, as seen in satellite imagery, is more than double that of the initial foothills convection.

In this paper, we propose a conceptual model of severe convective outbreaks in Alberta designed to aid forecasters in increasing the lead time on the issuance of severe weather watches and warnings. The model is based on the results of extensive analysis of data gathered during the mesoscale field experiment described below.

The LImestone Mountain EXperiment (LIMEX-85) and data analyses

LIMEX-85 was carried out from July 8 to July 23, 1985. The primary objective of the experiment was to obtain accurate surface and upper-air data of high spatial and temporal resolution over the Alberta foothills during days exhibiting a capping lid. A total of 9 upper air stations (radiosonde and airsonde) provided soundings at two hour intervals starting from 8 Local Daylight Time (LDT; 14 UTC) and ending at 18 LDT (00 UTC). The surface network was composed of several different components. Eight automated (CR-21) stations recorded five minute averages of temperature, humidity, and winds. Forestry service stations contributed manual observations twice daily (8:30 and 13:00 LDT). Surface hourly reports were also available at the normal operational stations run by the Atmospheric Environment Service of Canada (AES; see Fig. 1). The Alberta Research Council operated its 10 cm, S-band radar located at Red Deer (AQF) throughout the experiment. The digitized reflectivity data obtained from this radar (contoured in plan position indicator (PPI) format), along with both polar-orbiting and geostationary satellite imagery, permitted determination of the location and intensity of convection. The full observational network was in operation on 11 days. Hail fell in the project area on 9 of these days. Following the hail severity classification of Smith and Yau (1987), 5 days were classified as light hail days, 3 as moderate , and 1 (11 July 85) as severe. On the remaining 2 days only cumulus (CU) and towering cumulus (TCU) clouds were present. A total of 449 soundings were released during the entire experiment.

A standard set of horizontal and vertical cross section analyses were performed for each of the eleven case days at two hour intervals. The horizontal cross sections were constructed by interpolating the irregularly spaced data to a regularly spaced (0.14°) 20x20 grid mesh using a version of the Barnes scheme (Barnes, 1973). In these sections (see e.g. Fig. 2) the location of the upper air stations (denoted by *) and two of the surface stations (FMH and WBA, denoted by o) were plotted along with corresponding manual cloud and weather observations. The rectangle in Fig. 1 shows the region covered by the horizontal cross sections. The orientation of the foothills is northwest-southeast roughly parallel to a line running through the stations

ARL, LMW, AML, and FMH. Linear interpolation was used to construct the vertical cross sections with a vertical grid length of 10 mb. Sounding derived variables such as lifting and convective condensation levels (LCL and CCL), lifted parcel energy (LPE), etc., were determined numerically using algorithms given in Stackpole (1967).

The results of the analysis are given in Smith and Yau (1990) and will be presented at the workshop. In the following, we summarize the major findings in a conceptual model.

A conceptual model of severe convective outbreaks

The evolution of both the synoptic and mesoscale environment accompanying a severe convective event in Alberta usually takes place over the course of three to four days. This evolution can be described in terms of three separate stages, each typically lasting about one to two diurnal cycles.

Stage 1 in the evolution is characterized by the presence of an upper-level height and thickness ridge over Alberta. The subsidence associated with the ridge provides for generally clear sky conditions and a strong inversion which inhibits or "caps" deep convection. On days during Stage 1, therefore, convective activity is limited to cumulus, towering cumulus and possibly isolated thunderstorms.

By 12 LDT on a Stage 2 day, the thickness and height ridge has moved eastward. Part or all of the foothills region is located slightly downstream of the advancing upper-level thickness and height trough (Fig. 3a). Mostly clear skies prevail although some altocumulus clouds may be present. By this time, the atmosphere over Alberta has been affected by subsidence warming in the ridge for at least 24 hours. Thus the capping lid is often stronger than during Stage 1. Convection occurs first over the foothills, but on this day, the cooling aloft acts to destabilize the atmosphere allowing for large LPE and deep convection (Fig. 3b). Rapid vertical and horizontal growth of the mountain-plain circulation takes place effectuating an early (before 12 LDT) transition from downslope flow to upslope flow over the plains. This moisture bearing upslope flow, underruns the capping lid and reaches the foothills in time to reinforce the foothills convection. The end product, often seen in satellite imagery, is a vigorous squall line that propagates eastward with the westerly component of the mid-tropospheric winds.

On days during Stage 3, the upstream 500 mb height and thickness trough moves further into Alberta. The atmosphere is nearly convectively neutral and little or no capping lid is present. Widespread stratiform rain (convective debris) may persist in the morning accompanied by generally overcast conditions. Due to the cloudy conditions, the normal mountain-plain circulation is weakened or suppressed entirely. The absence of organized boundary layer flow greatly reduce the risk that the convection will grow to anything stronger than weak multicell storms.

Conclusions

Our analyses of high resolution surface and upper-air data gathered during the LIMEX-85 field experiment resulted in the following conclusions concerning severe convective outbreaks in Alberta:

1) Under generally clear sky conditions, cumulus convection begins over the Alberta foothills, where the capping lid is quickly eroded by strong surface heating.

2) Severe convective outbreaks occur when cooling aloft ssociated with an approaching synoptic-scale, upper-level trough is *in phase* with surface heating over the foothills. Such a configuration provides localized, deep destabilization which gives rise to an amplified mountain-plain circulation, underrunning, and the establishment of a positive feedback loop between the boundary layer and the free atmosphere.

3) The temporal and spatial resolution of the current operational upper-air and surface network in the region where convection first forms (i.e. the Alberta foothills) is inadequate for the purposes of forecasting the initiation of severe convection.

4) In spite of 3), lead time in the issuance of severe weather watches and warnings could be gained from early identification of a) *an advancing synoptic-scale, upper-level trough* in combination with b) *a strong easterly component of the upslope flow near the foothills*, an indicator of a rapidly intensifying mountain-plain circulation.

The Alberta mountain-plain circulation is another example of a wide class of mesoscale solenoidal circulations that, increasingly, appear to play a fundamental role in the initiation of severe convection. For Alberta, we have identified upper-level cooling associated with a synoptic-scale trough as the key factor in permitting such a circulation to amplify. It is of interest to know if such cooling is also operating in other areas (e.g. tornado alley in the United States) when differential surface heating induces underrunning and the subsequent triggering of severe convection. Such knowledge is vital in determining how to best utilize current and future observing systems for the purpose of forecasting severe weather.

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Fig. 1: LIMEX-85 mesoscale analysis domain (rectangle) and radar coverage (circle) with respect to the AES operational observing network in Alberta.

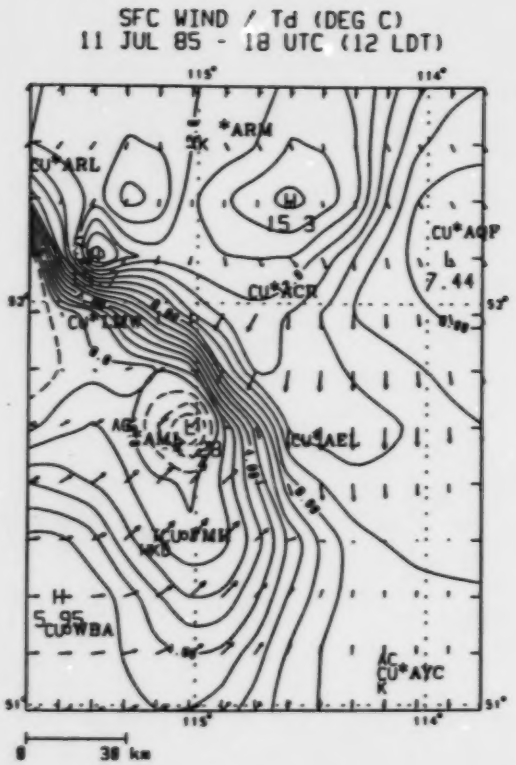

Fig. 2: Analyzed field of surface wind and dew point temperature at 18 UTC (12 LDT), July 11, 1989. Contour interval is 1°C. For surface wind vectors, 1 east-west grid length = 10.6 ms^{-1}.

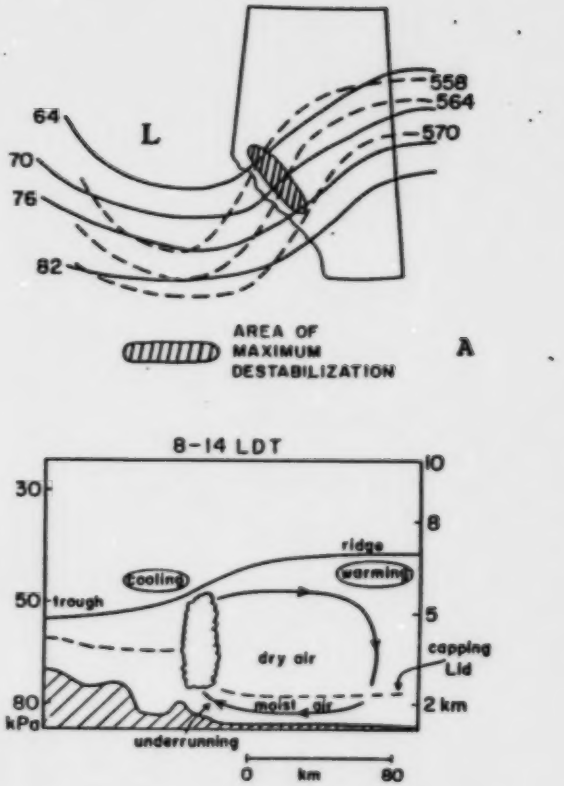

Fig. 3: (a) 500 mb height and 500-1000 mb thickness pattern on a day of a severe convective outbreak in Alberta. The area of maximum destabilization is located over the Alberta foothills where maximum upper-level cooling is superimposed over maximum surface heating. (b) Schematic vertical cross section for 8-14 LDT illustrating the amplified mountain-plain circulation and underruning induced by upper-level cooling and surface warming over the foothills.

LES DEPRESSIONS POLAIRES DANS L'EST DU CANADA

par

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Résumé: *Les dépressions polaires représentent un phénomène régulièrement observé sur les régions océaniques côtières de l'est du Canada en automne et en hiver. Après les avoir décrites, nous présentons les conditions synoptiques favorables à leur apparition et à leur développement. Le cas d'une dépression polaire typique qui s'est développée sur le nord de la baie d'Ungava le 3 octobre 1987 sera discuté du point de vue d'un problème de prévision. Dans cette perspective, à moyen terme, on peut reconnaître que la situation synoptique est propice à leur genèse. A court terme, on doit suivre les données de surface disponibles, dont les rapports de bateaux, mais surtout les images satellitaires. Enfin, une climatologie sommaire des dépressions polaires dans ces régions sera présentée.*

Abstract: *Polar lows are regularly observed over coastal waters off eastern Canada during fall and winter. After a description of this meteorological phenomenon, we shall present the synoptic conditions under which they appear and develop. A case study of a polar that developped over northern Ungava bay on October 3 1987 will be discussed as a forecastiong problem. In the medium range, we can recognize that the synoptic situation is favourable to their genesis. In the short term, we must rely on all available surface data including ship reports and, foremost, on satellite imagery. Finally, a succinct climatology of polar lows in these regions will be shown.*

INTRODUCTION

Les dépressions polaires sont un phénomène météorologique de l'échelle méso-α, elles ont typiquement un diamètre de 100 à 500 km. Ces dépressions, d'abord étudiées en Scandinavie dont elles frappent les côtes, sont souvent observées sur les régions océaniques de l'est du Canada. Elles ne doivent pas être assimilées à de simples dépressions thermiques

Fig. 1. Exemple de dépression polaire en spirales. Image IR NOAA 18/01/89.

Ces dépressions prennent, vues du satellite, deux aspects différents (Carleton 1985). Certaines montrent un panache nuageux en virgule alors que d'autres exhibent des bandes de nuages en spirale qui convergent vers un centre de rotation. Le centre de rotation apparaît nettement puisqu'il y a généralement peu de nuages au centre même. A l'occasion, on peut qualifier d'oeil ce centre sans nuages. Les bandes spirales, qui accompagnent aussi les dépressions polaires avec nappe nuageuse en virgule, sont formées de nuages convectifs. Dans le cas des systèmes spiralés surtout, il n'y a pas de grande masse de cirrus associée (fig. 1).

Les dépressions polaires en spirales sont les plus fréquentes sur l'Atlantique Nord. En général, l'influence de ces dépressions ne s'étend pas jusqu'à la haute troposphère. Elles se

développent rapidement et durent souvent moins d'une journéée. Vu leurs dimensions réduites et leur courte durée de vie , elles sont rarement analysées sur les cartes de surface des centres de prévision canadiens ou du Centre Météorologique Canadien.

CYCLOGENESE ET DEVELOPPEMENT

Voici l'environnement favorable à la genèse puis au développement des dépressions polaires, d'abord en surface puis en altitude.

Surface

En surface, les dépressions polaires se développenet dans une région où, à priori, la circulation est cyclonique. On retrouve généralement un fort gradient de température à bas niveaux qui se forme naturellement quand une masse d'air arctique envahit les régions océaniques non gelées ou encore les Grands Lacs. Le flux de chaleur sensible au dessus de l'océan amène le réchauffement de l'air nécessaire pour former ce gradient. De plus, ce réchauffement, s'il est limité géographiquement, engendre une cyclonisation de la circulation. Les conditions précitées se retrouvent avec l'advection d'air froid derrière une dépression extra-tropicale classique.

En altitude

Les dépressions polaires se développent généralement quand la circulation en altitude est plutôt faible et que le cisaillement vertical du vent n'est pas important. Il n'est pas absolument nécessaire d'avoir de l'advection positive de tourbillon mais de l'advection négative de tourbillon agit comme un frein. Les dépressions polaires se développent quand le dôme d'air froid, tel que perçu à 850 mb ou dans les épaisseurs 1000-500 mb, se superpose à la zone barocline formée dans les bas niveaux. A ce moment la stabilité statique de l'air diminue jusqu'à devenir instable.

L'arrivée du dôme d'air froid correspond à l'arrêt de l'advection d'air froid dans la région. Selon la théorie classique du développement de Sutcliffe ou Zwack, le laplacien des advections thermiques est alors favorable à la cyclonisation de surface. Rappelons que toutes les conditions précitées se retrouvent généralement derrière le passage d'un front froid suivi d'un dôme associé à une circulation fermée en altitude.

Cyclogenèse

Les flux de chaleur sensible concentrés dans ces régions permettent la cyclonisation de la circulation de surface mais ne réussissent pas à expliquer le développement rapide et intense des dépressions polaires. ainsi les dépressions polaires ne sont pas de simples dépressions thermiques. A cause de la baroclinicité de bas niveaux présente et l'apparition occasionnelle de virgules nuageuses, on explique en partie leur développement par un processus d'instabilité barocline classique et, vu la rapidité du développement, on les qualifie d'occlusions instantanées.

Cependant, on croit que la cause première de la divergence nécessaire à l'intensification de ces dépressions est due à la libération de chaleur latente par la convection dans la région soit donc par un processus d'instabilité conditionnelle de second type (CISK) (Rasmussen 1979, Sadie-Warner 1985). En fait. de la convection intense et concentrée accompagne ces dépressions. Le développement de la dépression polaire en un système organisé et intense se produit en même temps que la convection se développe.

ETUDE DE CAS ET PROBLEME DE PREVISION

Le 3 octobre 1987 une dépression polaire classique avec spirales s'est développée dans le nord de la baie d'Ungava. Nous la suivrons dans la perpective d'un problème de prévision.

Images satellitaires

La figure 2 montre la dépression polaire à trois stades différents. D'abord à 23:14Z le 2 octobre (fig. 2 a) , nous étions en présence d'une feuille barocline qui a l'allure d'une petite virgule. On verra qu'il y a un noyau de tourbillon sur la 500 mb. La dépression polaire naîtra de ce système nuageux en partie convectif. A 8:44Z le 3 octobre (fig. 2 b), la dépression est bien formée. Le développement s'est opéré en moins de 9 heures. Les spirales sont formées de nuages convectifs, probablement de TCu. A 18:41Z (fig. 2 c), on voit encore la circulation cyclonique mais les nuages font figure de débris par rapport à l'image précédente. La perturbation se désintensifie. la dépression aura vécue moins de 24 heures.

Cartes de surface

Nous avons souvent tendance à rejeter les rapports de bateaux qui ne sont pas conformes à notre appréciation du temps. Dans le cas présent. les relevés du Norman McLeod Rogers indiquaient nettement et correctement ce qui se passait dans le secteur. Ainsi à 03Z et 06Z (fig. 3 a et 3 b), on y enregistrait des vents d'est et des tendances de pression de 3.1 et 5,2 mb/ 3 hres à la baisse. Il y avait donc confirmation du développement d'une dépression tel que proposé par les images satellitaires. A 09Z (fig. 3 c), la dépression est à son maximum d'intensité et le bateau rapporte des vents de 45 noeuds et de la neige forte. A 18Z (fig. 3 d), la depression s'est affaiblie. Elle s'est déplacée vers l'est à une vitesse moyenne de 20 à 25 noeuds durant sa traversée.

Fig. 2. Images satellitaires NOAA IR du 2 et 3 oct 1987 à a) 23:14Z, b) 08:44Z et c) 18:41Z.

Cartes en altitude

A 850 mb (fig. 3 e), un dôme d'air froid, compte tenu de la saison et de la température de l'eau soit 2 à 3 °C, se déplace sur la baie d'Ungava. A 500 mb (fig. 3 f), un maximum de tourbillon traverse le secteur mais donne peu d'advection positive de tourbillon.

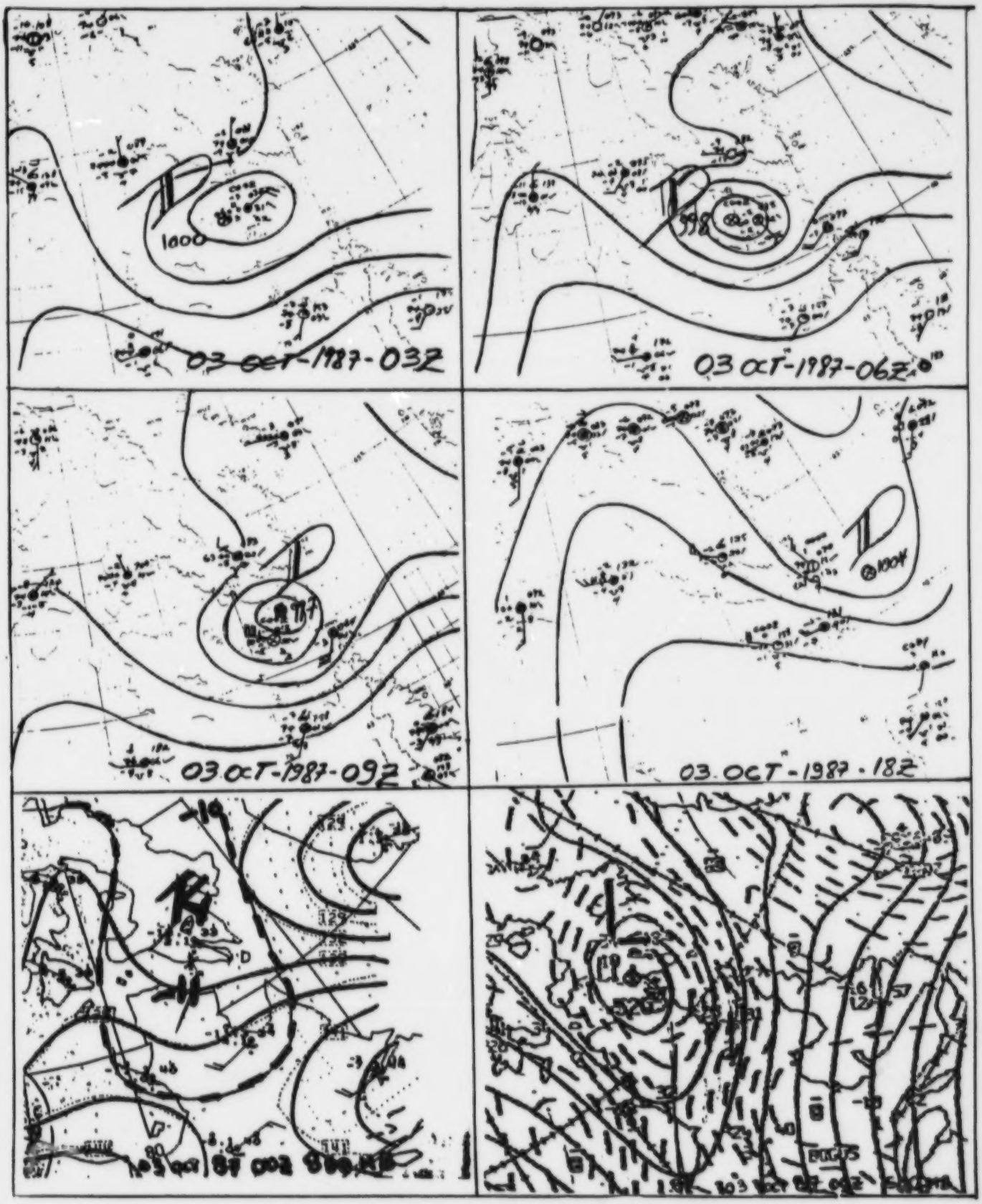

Fig. 3. Cartes de surface , de 850 mb et 500 mb du 3 oct. 1987.

Problème de prévision

Reconnaitre et comprendre ce qui se passe et ce que l'on voit sur les images satelitaires et les données de surface, c'est déjà un élément de prévision à court terme.

A moyen terme, on ne peut prévoir avec précision le lieu et le moment de la cyclogenèse d'une dépression froide. Cependant, on peut reconnaitre 24 heures à l'avance que les conditions synoptiques seront favorables à leur formation. Les modèles numériques, à défaut de bien prévoir la formation des dépressions polaires, prévoient avec suffisamment de précision les patrons synoptiques. Ainsi on pourra suivre les dômes d'air froid se déplacer sur des régions océaniques non gelées où la circulation sera cyclonique en surface et faible en altitude. Il se peut même que les modèles indiquent une dépression de surface timide dans ces secteurs.

A court terme, les conditions synoptiques étant favorables, on doit surveiller tous les rapports de surface, côtiers ou de bateaux, et les interpréter en conséquence. Surtout il faut scruter les images satellitaires qui sont souvent le seul, sinon le principal, outil de détection de l'apparition des dépressions polaires. Ainsi on pourra percevoir très tôt toute circulation cyclonique puis développement en bandes spiralées des nuages convectifs. Les dépresions polaires s'organisent souvent dans des régions où déjà les TCu (voire Cb)sont présents, parfois en rues où en bandes. A l'occasion, une nappe de nuages apparait et s'épaissit juste avant la cyclogénèse et de la circulation cyclonique (Fett 1987).

Ainsi, on peut, à court terme, aviser les utilisateurs de la présence de vents et de conditions météorologiques dangereuses.

CLIMATOLOGIE

La figure 4 montre le nombre de dépressions polaires traversant un carré de 100 km de côté entre septembre 1988 et mars 1990. Ce sont donc des données très fragmentaires, d'autant plus que les images satellitaires NOAA utilisées étaient parfois manquantes et de couverture temporelle non optimale. On notera tout de même des maxima dans la mer du Labrador et dans la baie d'Hudson. Cette dernière gèle en décembre et profite donc d'une saison écourtée. Durant cette période aucune dépression polaire n'a traversé le bassin de Foxe et la baie d'Ungava mais une a été observée sur le lac Supérieur pendant le mois de décembre 1989 qui a été exceptionnellement froid. Les mois de décembre, janvier, février et mars ont vu un nombre approximativement égal de dépressions polaires se développer soit 7 ou 8 en 2 saisons. En général, les dépresssions polaires se déplacent lentement vers l'est ou sont quasi-stationnaires.

CONCLUSION

En conclusion, on peut déjà prétendre prévoir l'apparition des dépressions polaires à court terme quoique la prévison demeure presqu'un exercice de suivi de la perturbation. Si on reconnait que ces dépressions polaires sont significatives, qu'elles

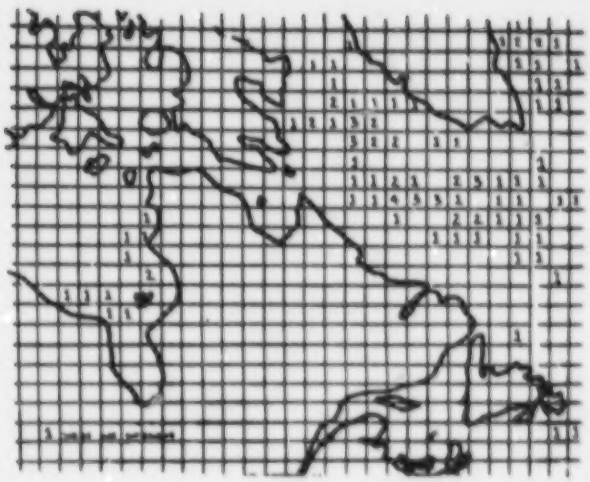

Fig. 4. Climatologie du nombre de dépressions polaires traversant un carré de 100 km de côté de septembre 1988 à mars 1990.

représentent un danger à la navigation, entre autre, et qu'elles sont différentes des dépressions extratropicales classiques, il faut mettre des efforts pour les étudier et mieux les prévoir. Les étudier, c'est aussi mieux comprendre comment s'opère le développement des dépressions atlantiques en général et des bombes en particulier. Beaucoup de dépressions intenses de l'Atlantique Nord ont le caractère explosif des dépressions polaires.

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A STUDY OF PHYSICAL PROCESSES ASSOCIATED WITH VARIABILITY IN ENSEMBLES OF LAGGED OPERATIONAL MODEL FORECASTS OF MARITIME CYCLOGENESIS

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1. ABSTRACT

Successive operational model forecasts of marine cyclogenesis, valid for the same 12 hour time period, were examined for one cold season for the Western Atlantic. The degree of forecast ensemble variability was not well related to the overall prediction error, belying the view that consistency in a sequence of forecasts indicates reliability. Preliminary attempts at understanding physical explanations of this variability will be presented through diagnoses of model forecasts for the ERICA IOP #2 cyclone. It is suggested that the complex synergism that exists between atmospheric processes may lead to a variety of model forecasts evolving from a given set of approximately equivalent large scale conditions, depending on the details of the initial atmosphere-ocean structure.

2. INTRODUCTION

Ample evidence exists to demonstrate that the more severe or 'explosive' occurrences of maritime cyclogenesis represent a serious hazard in the offshore environment. A recent example is the cyclone of 13-15 December, 1988 (ERICA IOP #2), in which two fisherman drowned and the 14000 ton drill rig Rowan Gorilla capsized while under tow. Considerable research effort has been exerted in an attempt to understand the dynamics of these cyclones. Simultaneously, operational numerical weather prediction models have improved their forecasts of explosive marine cyclogenesis in recent years to the extent that Sanders(1987) suggests that all of the physical ingredients, crucial to this cyclogenesis and evidently unique to the maritime environment (Roebber, 1989), exist in the models. However, despite these recent successes, as will be shown in this paper, considerable variability in predictions of cyclogenesis often exists for a series of forecasts (ensembles) valid for the same time period. The work reported in this paper represents an attempt to document the extent of this forecast ensemble variability for marine cyclogenesis in the Western Atlantic for the 1988-89 cold season, with a view towards gaining a physical understanding. Some preliminary diagnoses from the forecasts of the Canadian Meteorological Centre (CMC) Regional Finite Element (RFE) model for ERICA IOP #2, which represents a particulary notable example of this forecast variability, will be presented at the conference.

3. METHODOLOGY

Variability in Western Atlantic cyclogenesis forecasts was investigated in the NMC and CMC operational short-range models (the NGM and the RFE, respectively) for the period November, 1988 through March, 1989. All cyclones with an analyzed 12 hour maximum central pressure fall occurring within the region offshore of eastern North America and west of the model facsimile display boundaries (shown as the solid line in figure 3), were included in the study. Ground truth was based upon the six hourly manual NMC final surface analysis.

The 12 hour time period of cyclone maximum central pressure fall was chosen as the nominal period of interest, based on the assertion that a model's utility may best be defined by its ability to forecast significant change in a cyclone's intensity. The analyzed and modeled 12 hour pressure change data were then normalized to an equivalent pressure change at 60°N and compared for each ensemble of forecasts representing forecast ranges of 0-12, 12-24, 24-36 and 36-48 hours.

4. OBSERVATIONS VERSUS CLIMATOLOGY

Figure 1 shows the distribution of the analyzed central pressure fall and cyclone frequency as a function of date for the entire sample period. A frequency plot of the observed development is shown in figure 2, along with basic distribution statistics. Cyclogenesis spanned a wide range of intensities, from no development (1 case) to extraordinarily rapid development (greater than 24 mb in 12 hours, 13 cases). Offshore cyclogenesis was highly active beginning in mid-December, continuing after a short pause Christmas week through mid-February. Extraordinarily intense cyclogenesis occurred in mid-December and particularly, through the first three weeks of January, resulting in a total of 13 storms for the season that developed at a rate of at least 2 mb per hour for 12 hours. In the peak months of December-February, 11 of these particularly rapid developments occurred. Figure 3 shows the location of the mid-point of the cyclone maximum 12 hour deepening period. It is evident that Western Atlantic cyclone activity was occurring well-offshore, which resulted in anomalously low precipitation along the eastern seaboard for much of this period (see Climate and Diagnostics Bulletin, NOAA, 88-12 through 89-2).

A comparison of the 1988-89 cold season activity with climatology shows that this pattern is consistent with past experience. Hayden (1981) showed, using cyclone frequency data for the period 1885-1978, that the mean storm track runs along a line from Cape Hatteras to Halifax, but that considerable variability in cyclone frequency exists along the western boundary of the Gulf Stream, suggesting that an offshore storm track is an anomalous but not infrequent occurrence. Resio and Hayden (1975) showed that the seaward displacement of the mean storm track is associated with increased severity of Atlantic storms. Colucci's (1976) cyclone climatology, based on ten years of winter data, also shows the existence of two discrete cyclone tracks: a primary track along the continental margin and a secondary track along the western boundary of the Gulf Stream, the latter of which was characterized by more rapid cyclogenesis.

5. OBSERVATIONS VERSUS FORECAST

Corresponding model cyclone deepening distributions for each of the forecast ranges, (not shown) demonstrate a tendency in both models to under-forecast cyclone development. In the NGM, this is demonstrated by a monotonically decreasing mean 12 hour cyclone central pressure fall (or alternatively, an increasingly negative mean forecast pressure change error) with forecast range. In the RFE, this trend with forecast range is complicated by what appears to be a spin-up problem at 12 hour range, which shows performance levels degraded to that of the 48 hour forecasts. The data suggest that the RFE forecasts degrade somewhat less rapidly with time than the NGM, starting from nearly equivalent performance levels at 24 hour range. Clearly, the tendency of numerical models to underforecast maritime cyclogenesis, first noted by Leary (1971), has not yet been eliminated.

The model cyclone position forecasts for the four forecast ranges were also examined. At 12

and 24 hours, the NGM captured reasonably well the offshore cyclone track, while the magnitude of the events (as discussed above) were somewhat under-represented. In contrast, at 36 and 48 hours, the model cyclones were weakened and scattered to the extent that it is difficult to define a primary cyclogenetic zone. This can be quantified by counting the number of cyclones with a maximum deepening position within the latitude-longitude band 35-40N and 55-75W, a region of concentrated cyclogenetic activity in the analysis (15 storms). The NGM at 12, 24, 36 and 48 hour range produced 13, 13, 7 and 5 storms, respectively, in this region. These results indicate that the NGM tends to lose 'resolution' with increasing temporal range, in terms of both the position and magnitude of cyclogenesis.The behavior in the RFE is more complex. Counts in the same latitude-longitude band for the RFE at 12, 24, 36 and 48 hour range are 13, 10, 11 and 9 storms, respectively. The offshore cyclogenetic zone is generally maintained, but with varying success that does not degrade monotonically with increasing temporal range.

6. ENSEMBLE VARIABILITY

Figure 4 shows the lagged forecast ensemble mean absolute error as a function of the ensemble error standard deviation for each of the models; the plots thus indicate the ensemble accuracy along the abscissa and the variability of the forecasts along the ordinate. These statistics were computed over the ensemble of (usually) 4 forecasts for each of the 52 events. One might expect to see a strong relationship between the ensemble mean absolute error and the ensemble error standard deviation, since the accepted (and operational) view is that consistency in a sequence of model forecasts indicates reliability (Reed et al., 1988). However, these results show that the degree of variability in the forecasts is not well related to the overall prediction error, due to a number of ensembles of low variance and high error (consistent but poor forecasts of development) and ensembles of high variance and low error (inconsistent but within range of the observed development).

In terms of central pressure fall, the NGM and RFE forecasts for the ERICA IOP #2 storm represent two of the most highly variable ensembles in the 1988-89 season. However, as noted by Weinstein and Sanders (1989), wind speed is a more operationally useful measure of storm development and intensity than central pressure. The sequence of RFE forecasts (starting with the longest range) showed increases in the maximum surface wind speed of 53, 60, 34 and 19 knots over the twelve hours of most rapid development in this case. While difficult to specify precisely, measurements from ships and aircraft during this storm suggest that the observed maximum wind increase was on the order of 40-45 knots. Thus, the magnitude of the event was inconsistently forecast and not well defined. Since storm damage increases dramatically with wind speed (e.g. Leicester and Beresford, 1978), this level of uncertainty is problematic.

7. DISCUSSION

The most obvious cause of divergence in successive model forecasts of cyclogenesis is differences in the initial analysis, or more precisely, differences in the flow at the commencement of the period of rapid development resulting from either initialization or integration of the model equations from the initial state. Presumably, for most of these cases, in which the upstream flow is relatively well-sampled over the North American continent, initialization differences are small. However, it is widely accepted that the atmosphere is a nonlinear system that exhibits strong sensitivity to initial conditions (e.g. Lorenz, 1963, 1984). Explosive cyclogenesis is a process that can occur on a time scale of the order of 6-12 hours, yet there is evidence that such sensitivity to initial conditions can be significant even

in these circumstances (Reed et al., 1988; Mullen and Baumhefner, 1988 , 1989). It is possible that model runs may diverge over short time intervals as a result of subtle differences in the initial conditions feeding back into the evolution of the flow. This complex synergism within the atmosphere suggests that correctly simulating particular details of the mesoscale maritime environment may be crucial to achieving further forecast gains. This topic will be discussed further at the conference with reference to diagnostics computed from the RFE simulations of IOP #2.

8. ACKNOWLEDGMENTS

Thanks are due to Professor John Gyakum, McGill University, for his guidance, and Michel Jean, AES, and Richard Grumm, NMC, for their help in filling in gaps in the McGill model archive. This work has been supported by the NSF under grant ATM-8814816, NSERC under operating grant P0037433, and by an AES subvention.

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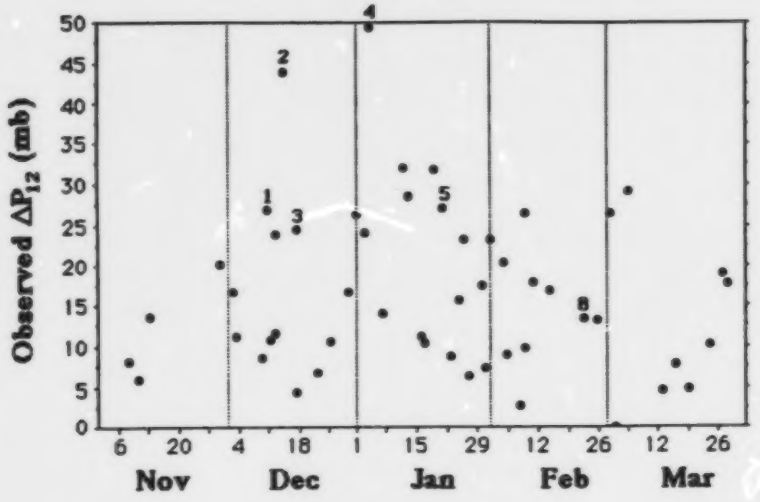


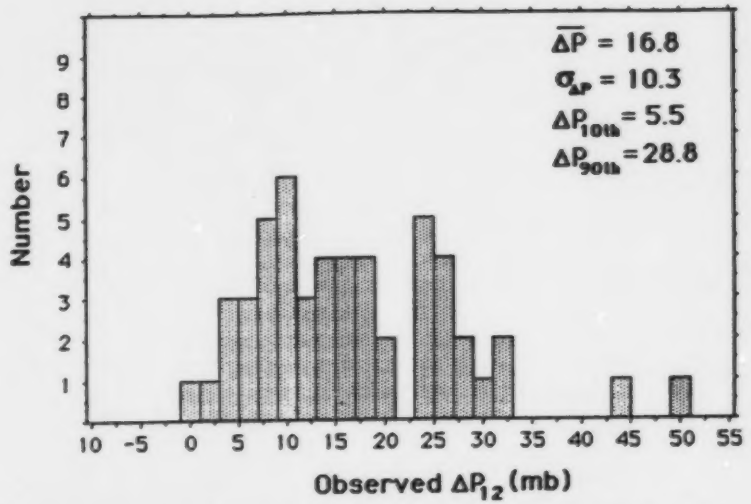


Fig 2: Frequency plot of observed 12 hour central pressure fall for the Western Atlantic 1988-89 cold season cyclones. Statistics are: the mean (ΔP), standard deviation ($\sigma_{\Delta P}$), and the 10th (ΔP_{10th}) and 90th percentile (ΔP_{90th}) central pressure falls.

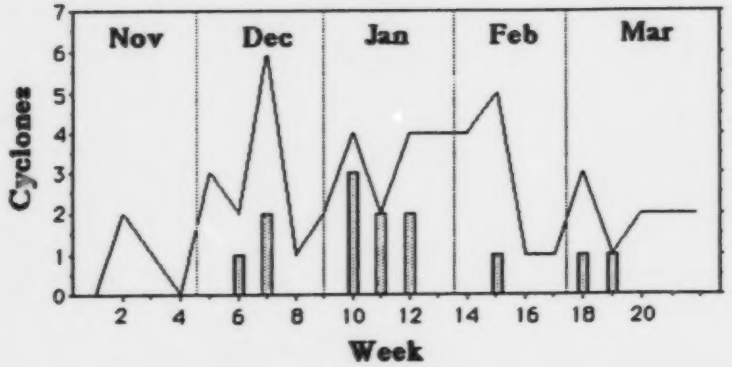


Fig 1: (a) Distribution of Western Atlantic cyclone maximum analyzed 12 hour central pressure fall for the 1988-89 cold season. Labelled points indicate ERICA IOP number. (b) Number of cyclones per week for the 1988-89 cold season. Bars indicate the number of cylones with 12 hour central pressure falls greater than 24 mb.

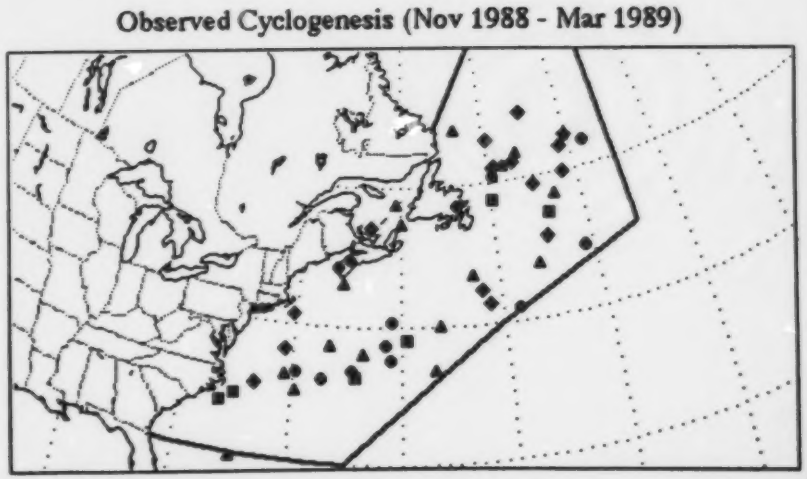


Fig 3: Maximum deepening positions of Western Atlantic 1988-89 cold season cyclones. The bold line indicates the study boundary and the symbols correspond to 12 hour cyclone central pressure falls of less than 6mb (■), 6-12 mb (▲), 12-24 mb (♦) and greater or equal to 24 mb (●).

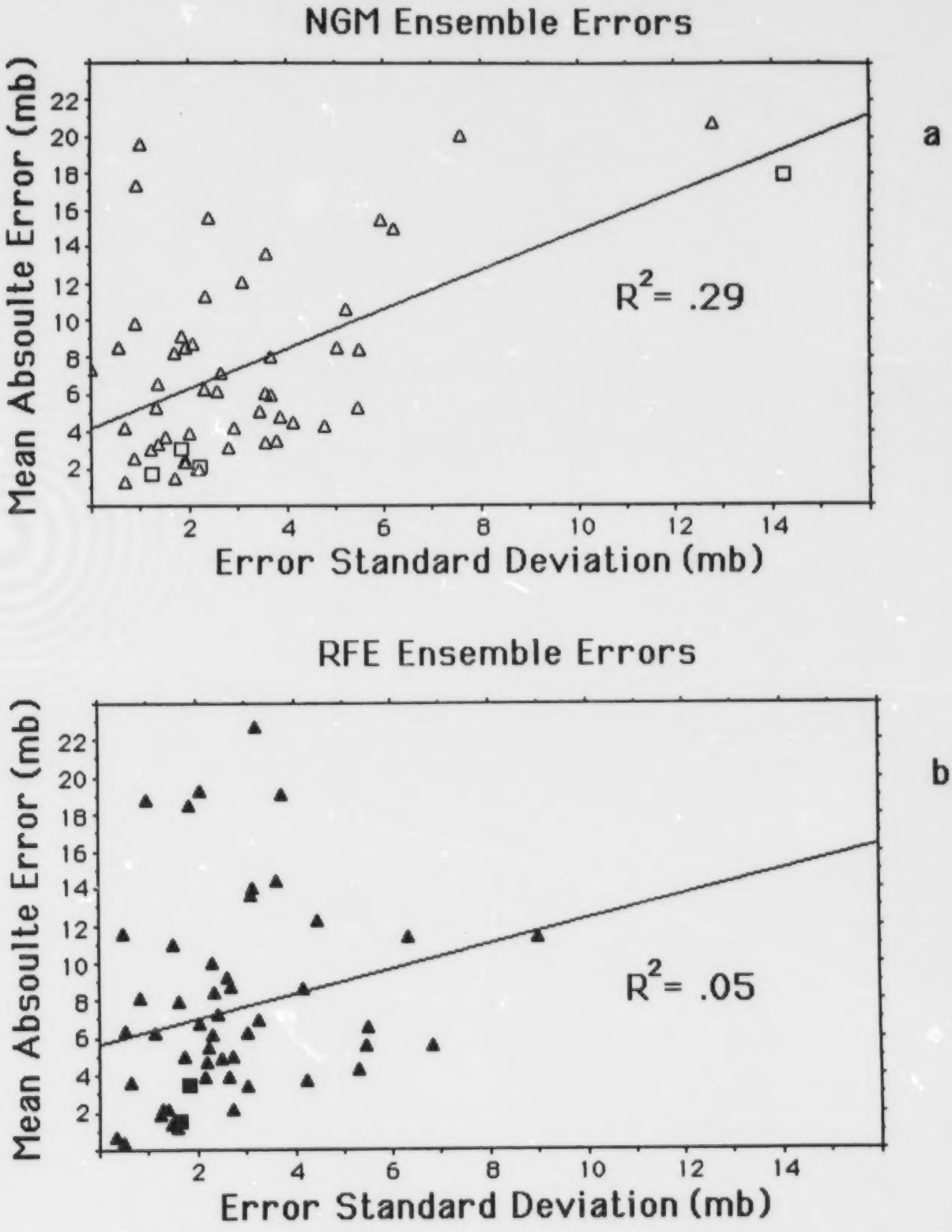


Fig 4: Ensemble mean absolute error versus ensemble error standard deviation of (a) NGM and (b) RFE 12 hour cyclone central pressure falls for the 1988-89 Western Atlantic cold season. The triangles indicate all four forecasts were available and the squares indicate only three of four forecasts were available. R^2 represents the square of the linear correlation coefficient.

MONITORING AND QUALITY CONTROL OF METEOROLOGICAL DATA AT CMC

Charles J. F. Anderson and Robert A. Mailhot,
Monitoring and Quality Control Section.

Abstract

The importance of having meteorological observations of high quality for NWP has taken on renewed meaning, because as the accuracy and resolution of forecasts from NWP models increase so does the need to ensure that only the most probably correct data are used in objective analyses. More conventional checks in decoding and rejections on analysis have always been part of the operations at CMC, but increasingly monitoring of residuals from more accurate trial fields is paying dividends in detecting more subtle behaviour of instruments and their readings.

Résumé

L'acquisition des observations de qualité élevée dans la production des PNT, connait un regain d'importance avec l'augmentation de la précision et de la résolution des prévisions faites avec les modèles numériques qui exige qu'on s'assure que seulement les données les plus probablement correctes sont utilisées dans l'analyse objective. Dans les opérations au CMC, on a toujours utilisé des méthodes plus conventielles de vérification dans le décodage et les critères de réjection à l'analyse mais, de plus en plus, l'examen des résidus venant de champs d'essai plus précis nous permet de déceler les comportements plus subtils des instruments et des données qu'ils produisent.

INTRODUCTION

The history of NWP over the last thirty years shows that the forecasts from numerical models have improved mainly because of intensive research into objective analysis schemes, the dynamics, physics and numerical methods within the models and due to increases in their vertical and horizontal resolutions. Thus the error of a six hour forecast or trial field in the analysis cycle now approaches the observational error for such parameters as height, wind and temperature from some sources of observations. Consequently tighter controls are having to be applied in their assimilation in order to accept the best data without rejecting consistent data that may differ from the trial field due only to an unpredicted meteorological development. Such fine controls nevertheless necessitate a closer monitoring of the performance of the various sources, because a degradation in their quality and possibly their number due to other causes could significantly jeopardize the total data base over time.

Thus the methods that are used to ensure the integrity of the data are a mixture of real and non-real time monitoring of the reception of the data and of the quality control that is performed on them at various stages within the NWP process. The importance that has recently been attached to these activities has led to considerable international cooperation to improve the overall quality of all meteorological data.

MONITORING ACTIVITIES

An overview of the flow of data at CMC from reception through to their objective analysis has already been written*. This poster presentation will show some results from monitoring the data as they pass through these processes.

Reception and Decoding

Before an analysis of meteorological observations is performed, it is preferable to have the maximum amount of data over an area, large enough to encompass the meteorological systems that are likely to affect the point or region of interest over the desired length of the ensuing forecast period. One way of monitoring this is to display all data received by the operational cut-off time with distinguishing symbols for each type of observation. A record of the running means for the total and number of each type is also kept.

This display gives an indication of the areas of good and poor coverage, but this is complemented by an annual monitoring of the performance of the GTS in relation to timeliness and a standard set of bulletins and observing stations. Each meteorological centre records the reception of these bulletins and reports from the stations within specific time periods. This can pinpoint the weak links in the GTS and possible causes, so that WMO can request countries to take corrective action.

During decoding, the coded reports undergo checks as to their compliance with coding regulations and the resulting individual observations pass through various physical and climatological tests. These include verifications against a dictionary of stations and checking for reasonable coordinates for transients. If observations fail these tests, flags are set in the data base where they are stored with the original decoded values. Queries to the data base provide statistics on the number and timeliness of received reports of each type of observation and on their quality. These can even bring to light delays within the CMC computing complex.

* Mailhot, Robert, 1989, Meteorological Data at the CMC: from the Receipt to Objective Analysis. The Monthly Review, Vol. VIII, #8.

Merging and Preparing Data for Analysis

Since some observations, such as surface synoptic and upper air, are taken separately but at the same geographic location, they are combined together to form a single profile for identified stations. This process eliminates duplicate observations at the same level but contained in different parts of the reports. No statistics are yet compiled at this stage of quality control, but a possible example would be to identify those stations that report significantly different surface pressures between their synoptic and radiosonde reports.

The final step, before presenting the data to the objective analysis, is to reduce further the profiles of multi-level data to pre-determined pressure levels: 1025 hPa to 100 hPa at 25 hPa intervals and 70, 50, 30, 20 and 10 hPa. This can, under certain conditions, involve vertical interpolation, either linearly or by integrating the hydrostatic equation. Any failures at this stage will cause flags to be set and stored in a file along with any others transferred from preceding stages. This file with screened observations of heights, temperatures, moisture and wind velocities and their associated flags from quality control serves as input to the objective analysis.

QUALITY CONTROL IN THE OBJECTIVE ANALYSIS

Up to this point, the meteorological data has undergone various internal checks for quality, but the objective analysis performs perhaps the most stringent test of all by comparing the data to both a trial field and neighbouring observations. As the errors in current trial fields approach some observational errors, the difference between observations and these fields, or residual, has become an important measure of quality.

Residuals and Rejections

After adjusting various remaining off-level data to the nearest level used in the objective analysis, the software computes residuals for all observations at one level or another. These residuals are then subject to both horizontal and vertical checks to determine whether the observations should be rejected or not. Such rejections will be familiar to operational meteorologists, since they are depicted on CMC upper air analyses in an opposite font to accepted data and the whole station plot is surrounded by a dotted circle.

Monitoring

While the number of rejections for a station over an extended period such as a month is one valid measure of overall quality, this can be complemented by statistics derived from residuals.

However there are several possible residuals between observations and various forms of an analysis. The ones, that are presently archived at CMC, are those with respect to the trial field for northern hemispheric rawindsonde stations, and from which the latitudinal bias within a 15 degree band has been subtracted. They exist for geopotential height, temperature, dew point depression and wind components at all mandatory levels from 1000 to 50 hPa, except 70 hPa, and at both 0000 and 1200 UTC.

There are numerous ways in which this kind of quality control can be monitored, although international standards through WMO are being formulated as now exist for verifications. The most common statistics that are used are the bias, RMS and standard deviation. The subtlety of some of the problems that can occur to radiosonde observations requires tracking their history over time. The vertical profile of these statistics for individual stations can, for example, also reveal the need for corrections to observations at high altitudes due to solar radiation or the drift of particular instruments. Geographical displays are other useful tools to pinpoint potentially problematical observations among their neighbours.

The residuals do not actually include those with respect to rejected observations, but with a few assumptions it is possible to infer the number of rejections over the monitoring period in comparison with the number accepted. These rejections though could include gross errors initially in the observations, but despite this, stations which exhibit statistics exceeding certain criteria can still be detected. In several meteorological centres, such stations form a "black list" so that the objective analysis does not consider them until their observations improve.

CMC has yet to take similar steps, but we are developing other potentially useful tools so that we can participate fully in the international, national and regional exchange of information on quality control and monitoring of observations. This should lead to an improvement in the quality of both the observations and the objective analyses and consequently the numerical forecasts.

CONCLUSION

Monitoring and quality control of meteorological data at CMC occur at almost all stages from reception through decoding and collation to the final objective analysis. Renewed emphasis both here and internationally through WMO in these activities is providing ways to maintain and improve timeliness, quality and to a certain extent coverage of meteorological observations. In an era when a few more suitably located observations have produced, in later studies, a significant effect on resulting numerical forecasts, extending the repertoire and monitoring the residuals of observations other than from rawindsondes should have similar benefits on our operational NWP forecasts.

STAND-ALONE LIGHTNING DETECTION EQUIPMENT

By: Pierre Pommainville
Canadian Forces Forecast Centre Trenton

In 1989, the Canadian Forces provided to 13 air bases across the country (and 2 in Germany) a complete LLP * lightning detection system. This system is used the weather by office or centre located on each base to detect cloud to ground (CG) lightning strikes. A thunderstorm weather warning is issued when CG strikes are expected to occur within 5 nautical miles (NM) of the base. During that period, refueling or arming an aircraft is strictly prohibited. Moreso, it is a normal procedure to switch to back-up electrical supply in order to prevent power surges or outages. A demonstration of this system will be held in poster session 2A using a case which occurred on 7 July 1989 in eastern Ontario.

Les Forces armées canadiennes ont équipé 13 aéroports militaires au pays (et 2 en Allemagne) d'un système complet de détection d'éclairs en 1989. Ce système est utilisé par le bureau ou centre météorologique situé sur chaque base dans le but de détecter des éclairs touchant le sol. Un avis météorologique d'orage est émis chaque fois que la foudre est prévu à l'intérieur de 5 milles marins de la base. Pendant ce temps, l'approvisionnement en carburant et en armement des avions est strictement interdit. De plus, on utilisera les génératrices d'urgence pour la prévention de pannes de courant. Il y aura une petite démonstration de ce système de protection a la session d'affichage 2A en utilisant un cas survenu le 7 Juillet 1989 dans l'est de l'Ontario.

* LLP: Lightning Location and Protection, Inc. Tucson, Arizona

LIGHTNING DETECTION THEORY

Lightning generation

One of the most widely accepted theories regarding charge separation in a thunderstorm is based on the phase change of water. The gravitational field combined with the convective current within a thunderstorm will locate the ice crystals (light) charged positively at the top of the cloud and the hail and super-cooled water droplets (heavy) charged negatively in the lower section. Since the cloud base is charged negatively, positive charges at the surface of the earth will move with the cloud and rise up in higher conductive areas such as trees, towers etc. The first lightning probably occurs within the cloud itself. More negative charges are concentrated in the base and finally when the charge difference between the cloud base and the ground reaches about 1,000,000 volts/metre the electric field breaks down and a CG lightning stroke is generated.

Capt Murphy J.D. 1988: "Lightning detection system acquisition and application", 5th Weather Wing Forecaster Memo, USA.

The lightning strike

The CG strike starts when a beam of negatively charged particles advances downward in 50 to 100 metre steps. This beam will seek a path of lower resistance which could create many branches. When the main branch reaches about 50 metres of the ground, an upward core (return stroke) of positive charges will rise to complete the circuit and move up the channel. During the flash, the temperature in the core could reach 3 X 10 to the 11th degrees Celsius. Negative charges are transferred to the ground resulting in a negative CG strike. The strike is not completed as positive streamers at the top of the channel probe the cloud for additional concentration of negative charges. Another dart leader goes down and another return stoke of positive charge is triggered. Depending on the cloud several return strokes are possible.

Capt Murphy J.D. 1988: "Lightning detection system acquisition and application", 5th Weather Wing Forecaster Memo, USA.

THE STAND-ALONE LIGHTNING DETECTION EQUIPMENT

The LLP thunderstorm sensor

The lightning detection process begins when the enormous electrical currents (up to 200,000 Amperes) associated with the lightning return stroke radiate radio frequency energy across a broad spectrum range (from 1 to 350 kHz). The incoming signals are analysed by the sensor's discrimination logic circuits, and signals which do not meet waveform criteria of a return CG stroke are rejected. Since a flash may be composed of a number of return strokes, a processing algorithm associates all strokes with the flash event in which they occurred. Thereafter, the direction and range are computed.

The direction of the CG lightning is determined by using a two orthogonal magnetic loop (north-south and east-west) antenna to sense the radiated wideband magnetic field change from a CG lightning. The electric field signal is measured by a flat plate antenna and used with a statistical distribution of the intensity of the magnetic signals to compute the lightning range. Flash polarity is considered in determining the range. Since signal intensity characteristics depend on polarity, positive and negative flashes are processed seperately.

Lightning Location and Protection, Inc (LLP), technical paper.

The LLP system operation

The LLP lightning display system is represented on the last page of this paper. The rings on the screen are the 0 to 5, 5 to 10, 10 to 30 and the 30 to 100 NM ranges centered on the sensor. The direction is separated into eight quadrants N, NE, E, SE, S, SW, W and NW. The exact direction and distance of the CG strike is not specified. The lightning flash count (number shown in the quadrants) is the count of CG strikes during the last 15 running time minutes. The screen is updated every 20 seconds. However any strikes within 5 NM will be displayed immediately. The following table represents the threshold flash count for each intensity level (ie strikes per 15 minutes).

		0-5NM	5-10NM	10-30NM	30-100NM
Green	(NONE)	0	0	0	0
Yellow	(OCNL)	*A*	1 to 5	1 to 10	1 to 50
Orange	(MDT)	*B*	6 to 10	11 to 20	51 to 100
Red	(FQT)	*C*	> 11	> 21	> 100

A when 2-3 adjacent octants are receiving strikes
B when 4-5 adjacent octants are receiving strikes
C when 6-8 adjacent octants are receiving strikes

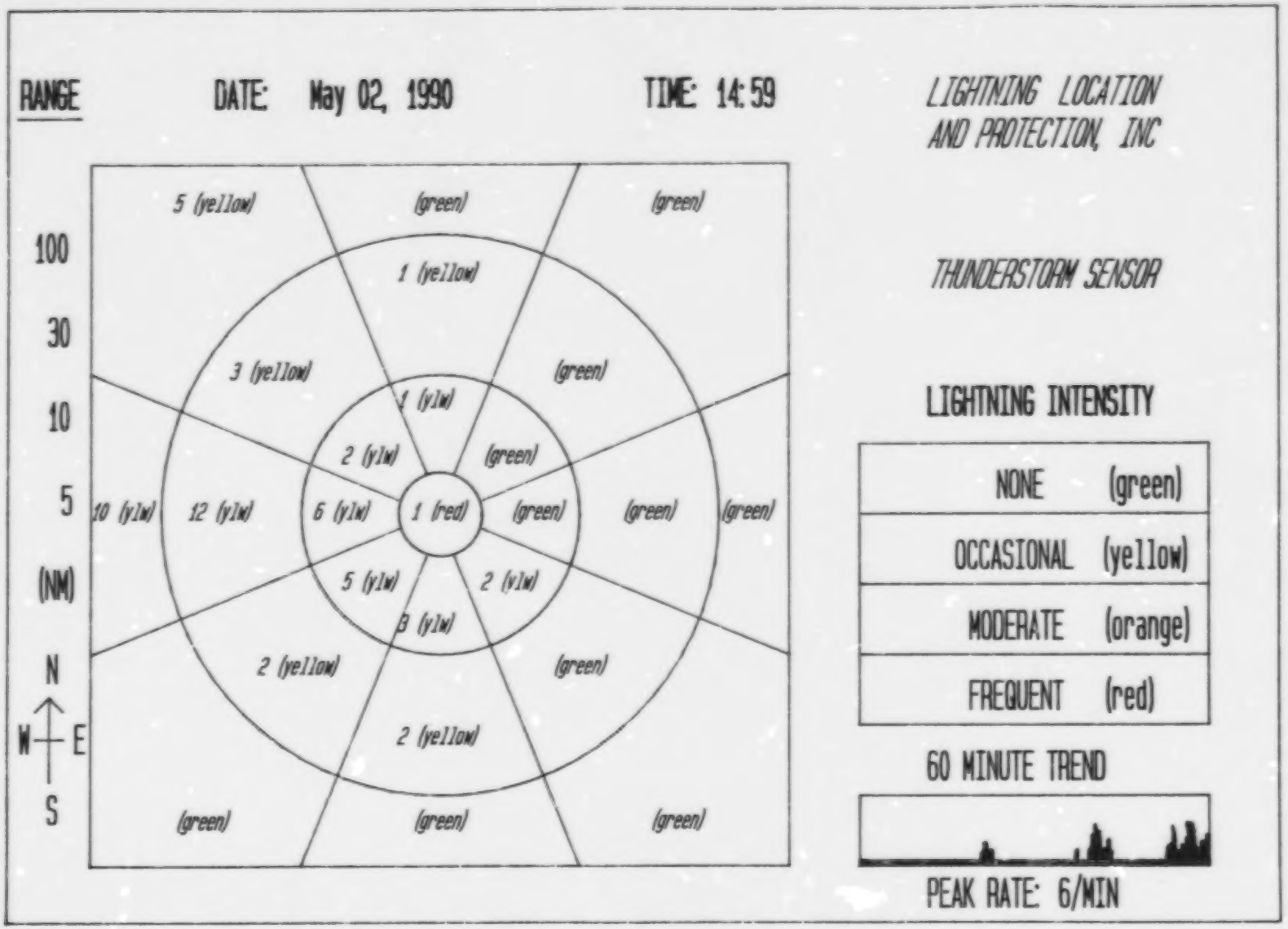
-The total geographical area of an octant increases as the range increases so the flash count threshold vary accordingly.

-An audible alarm will sound when the flash count has reached the frequent stage (red) in the 5-10 NM range or an overhead (0-5 NM) strike occurs.

The 60 minute trend in the lower right corner represents the last hour's total lightning flash activity. The peak rate number is the highest total lightning count recorded in minute periods during the last hour. The time zero is on the right while T-60 is on the left.

DEMONSTRATION

On the seventh of July 1989, an east-west polar cold front crossed eastern Ontario counties in the morning at about 12Z. A line of scattered thunderstorms developed along the front which moved southward at about 20 knots. The LLP lightning detector located at CFB Trenton showed many lightning strikes in the vicinity of the base. This was also confirmed by the King City radar and its lightning detector. In early afternoon, the maritime cold front which was located about 100 NM further north, slided down towards the base. This cold front was much more active producing several thunderstorms with hail, heavy downpours and some flooding in the region. Although unconfirmed, the Trenton forecast centre received a report of a funnel cloud located over Prince Edward county. The CFB Trenton LLP lightning detector reacted fairly well to the storms. This will be shown in a demonstration in session 2A.


RANGE
DATE: May 02, 1990
TIME: 14:59
LIGHTNING LOCATION AND PROTECTION, INC
THUNDERSTORM SENSOR
100
30
10
5
(NM)
N
W
E
S
5 (yellow)
(green)
(green)
1 (yellow)
3 (yellow)
(green)
1 (ylw)
2 (ylw)
(green)
10 (ylw)
12 (ylw)
6 (ylw)
1 (red)
(green)
(green)
(green)
5 (ylw)
2 (ylw)
8 (ylw)
2 (yellow)
(green)
2 (yellow)
(green)
(green)
(green)
LIGHTNING INTENSITY
NONE (green)
OCCASIONAL (yellow)
MODERATE (orange)
FREQUENT (red)
60 MINUTE TREND
PEAK RATE: 6/MIN

REDACTION AUTOMATISEE DE PREVISIONS METEOROLOGIQUES EN LANGAGE STRUCTURE (RAPELS)

Richard Verret

Section du développement des produits d'éléments du temps
Division du développement
Centre météorologique canadien

RESUME.

Le Centre météorologique canadien a développé un système de rédaction automatisée de prévisions météorologiques pour le public en langage structuré (français et anglais). La version actuelle du système est complètement objective et extrait toute l'information nécessaire à la rédaction des prévisions à partir d'une matrice contenant des prévisions d'éléments du temps sous forme digitale à toutes les trois heures.

The Canadian Meteorological Centre has developed an automated system to compose plain language public forecasts in French and English. The actual version of the system is completely objective and extracts all the necessary information to write a public forecast out of a matrix which contains digital forecasts of weather elements at every three hours.

1.0 INTRODUCTION.

Le système RAPELS (Rédaction Automatisée de Prévisions en Langage Structuré) permet de rédiger des prévisions météorologique pour le public, selon le format général prescrit par le Service de l'environnement atmosphérique du Canada (SEA) (MANPUB, 1988). Le système RAPELS est complètement objectif, et ne fait pas appel à l'intervention humaine. Toutes les informations nécessaires à la rédaction des prévisions publiques sont fournis par un modèle moteur, et par un système de prévision statistique piloté par ce même modèle moteur. La version actuelle du système RAPELS utilise le modèle spectral canadien (Daley et al, 1976) et le système de prévision statistique, basé sur l'approche "prévision parfaite" (Verret, 1987, 1988; Brunet, 1987). Les informations nécessaires au système RAPELS sont présentés sous forme de prévisions d'éléments météorologiques à 264 stations canadiennes, disponibles à toutes les trois, six ou douze heures couvrant la période d'intérêt. Ces prévisions d'éléments météorologiques constituent ce qui est convenu d'appeler la matrice d'éléments. Dans le futur, des interfaces seront développées, permettant aux usagers d'intervenir dans le processus de rédaction des prévisions, en modifiant la matrice d'éléments.

Le système RAPELS peut servir de guide prévisionnel, en intégrant dans un texte simple, tous les systèmes objectifs de prévision. Il permet aussi de standardiser le vocabulaire utilisé par les différents météorologistes opérationnels oeuvrant dans un même centre de prévision. Il peut servir d'outil de travail. Rapels permet aussi d'éliminer la traduction des prévisions. Finalement, RAPELS facilite la vérification des prévisions, celles-ci étant disponibles sous forme digitale dans la matrice d'éléments.

Les prévisions préparées par le système RAPELS couvrent les jours 1, 2 et 3, divisés en périodes de douze heures. RAPELS est conçu pour faire des prévisions pour 264 stations canadiennes, et dans le futur pourra faire des prévisions pour 197 régions au Canada.

2.0 MATRICE D'ELEMENTS.

Une matrice d'éléments est constituée pour chacune des 264 stations canadiennes, et éventuellement pour chacune des 197 régions couvrant le Canada. Les éléments contenus dans la

matrice d'éléments couvrent toutes les périodes de douze heures, du jour 1 au jour 3 inclusivement.

Les éléments météorologiques contenus dans la matrice sont:

- les climatologies des températures maximales et minimales.
- les fréquences climatologiques de précipitations.
- les températures ponctuelles.
- les températures maximales et minimales.
- l'opacité totale ponctuelle des nuages.
- les probabilités de précipitations sur 6 et sur 12 heures.
- les quantités totales de précipitations.
- les quantités de précipitations dues à l'instabilité.
- le type de précipitations et un accompagnateur.
- l'écart du point de rosée à la surface.
- les épaisseurs 1000-500 hPa.
- les épaisseurs 850-700 hPa.
- les épaisseurs 1000-850 hPa.
- la pression au niveau moyen de la mer.
- les vents (direction et vitesse).

Tous ces éléments sont fournis par le modèle spectral canadien et par le système de prévision statistique basé sur l'approche "prévision parfaite" développé au CMC. Tous les éléments sont disponibles à toutes les trois heures, sauf les probabilités de précipitations et les températures maximales et minimales. La matrice d'éléments ainsi construite, sert de base à la rédaction des prévisions. Un ensemble de règles a été développé pour en extraire toute l'information nécessaire à la rédaction d'un texte devant constituer les prévisions publiques.

3.0 REDACTION DES PREVISIONS.

Une base de connaissance, constituée d'un ensemble de règles heuristiques, a été construite pour examiner la matrice d'éléments. Ces règles permettent de traduire en langage clair toute l'information qui est disponible dans cette matrice. Des règles spécifiques ont été développées pour chacun des types d'éléments du temps retrouvés dans les prévisions publiques. Des règles sont aussi prévues pour s'assurer que le module d'écriture obéisse aux lois grammaticales et syntaxiques du langage. Le dictionnaire contenant les mots, les expressions et les phrases servant à la rédaction finale des prévisions, est bilingue, et les prévisions peuvent être écrites en français et en anglais.

Les éléments du temps décrits dans les prévisions publiques rédigées par RAPELS sont toujours, dans l'ordre: nébulosité et précipitations, quantités de précipitations, vents, températures et probabilités de précipitations. La description de la nébulosité peut être absente, si les précipitations sont importantes. En corollaire, seule la description de l'état du ciel est faite, s'il n'y a pas de précipitations prévues. La description des vents est absente dans les situations où leur vitesse prévue est inférieure à un certain seuil. Les quantités de précipitations prévues sont décrites seulement lorsqu'elles dépassent un certain seuil prédéterminé. D'autre part, les descriptions du régime de température et des probabilités de précipitations sont toujours présentes. Le système RAPELS ne permet pas de modifier l'ordre des éléments du temps décrits dans les prévisions.

Il n'y a qu'un seul degré de complexité des phrases décrivant la situation météorologique. La complexité des phrases désigne ici le degré de détails nécessaires pour décrire correctement

la situation météorologique prévue. C'est la situation météorologique en temps réel qui contrôle le degré de complexité des phrases.

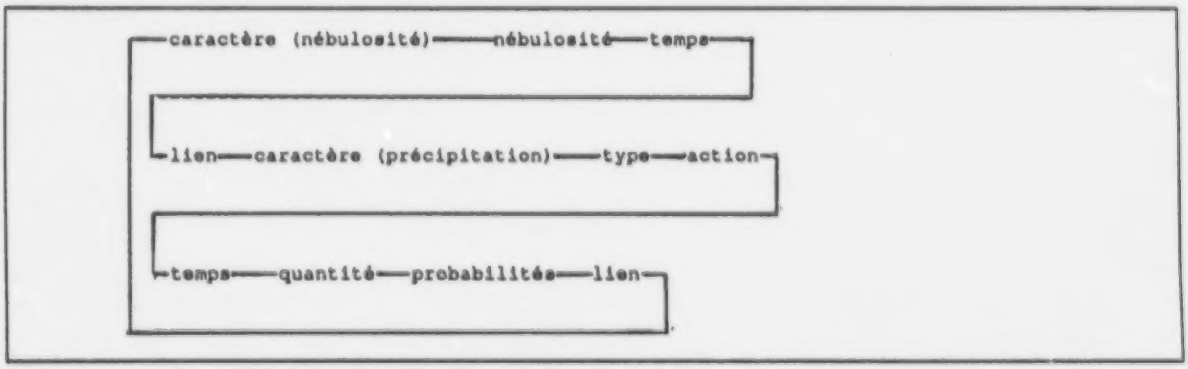
RAPELS n'est pas habilité à décrire les avertissements ou veilles météorologiques parce qu'il faut d'abord élaborer un système de suivi pour ces entités. Ce problème sera solutionner dans une version future de RAPELS. De plus, le système RAPELS ne peut faire de prévisions de gel, ni d'humidité. Ces variables pourront être prises en charge par RAPELS, dans un avenir rapproché. Aucune particularité régionale quant au choix des mots n'est permise.

3.1 NEBULOSITE ET PRECIPITATIONS.

Les descriptions de la nébulosité et des précipitations sont faites ensemble, ce qui permet de les rendre tout à fait conformes, même si les éléments insérés au départ dans la matrice ne le sont peut-être pas. Le type de précipitations est déterminé en utilisant les sorties directes du modèle moteur selon une approche diagnostique (Koclas, 1987), puis ajusté en fonction des températures basées sur l'approche statistique, qui apparaissent dans la matrice d'éléments. Le type de précipitations est déterminé à chaque trois heures, et inséré dans la matrice d'éléments, même si les quantités de précipitations prévues par le modèle moteur sont nulles. Ceci permet de prévoir des précipitations, ou des possibilités de précipitations, même si le modèle moteur n'en prévoit pas.

Un accompagnateur au type de précipitations est aussi déterminé de façon diagnostique à partir des sorties directes du modèle moteur, et placé dans la matrice d'éléments. Cette variable permettra d'insérer dans les prévisions publiques, des termes comme poudrerie, brouillard ou orage par exemple. Le choix du type de précipitations apparaissant dans le texte des prévisions, tient compte de l'accompagnateur.

La formation d'une ou de plusieurs phrases décrivant la nébulosité et les précipitations pour chaque période de douze heures, se base sur onze variables, qui peuvent se répéter séquentiellement plusieurs fois. Les onze variables suivent la séquence suivante:



Un vecteur de 11 éléments, replié sur lui-même, forme ainsi une chaîne de variables qui contient toute l'information nécessaire permettant la description de la nébulosité et des précipitations. Le nombre de repliements du vecteur de variables est déterminé par les règles de la base de connaissance et varie selon la situation météorologique à décrire. Il devient possible d'augmenter ou de diminuer la complexité des phrases, en contrôlant le nombre de repliements du vecteur. Les onze types de variables apparaissant à chaque repliement dans une chaîne sont décrits comme suit:

• caractère: cette variable apparaît deux fois,, et l'approche diffère selon les éléments à étudier et est un qualificatif s'appliquant sur la nébulosité et/ou les précipitations. Par

exemple cette variable permettra d'écrire le mot quelques devant "passages nuageux" ou devant "averses".

• **nébulosité**: décrit l'état du ciel. Cette variable est aussi utilisée pour décrire une évolution (action) de l'état du ciel. Par exemple, l'expression nébulosité croissante, qui a un caractère actif, est une description de l'état du ciel, dans le sens entendu ici.

• **temps**: cette variable apparaît deux fois et donne la période pour laquelle la description de la nébulosité et/ou des précipitations s'applique. Par exemples: nébulosité croissante ce matin ou averses cet après-midi.

• **lien**: cette variable apparaît deux fois et fait le lien entre la nébulosité et les précipitations ou entre deux phrases sur la nébulosité. Cette variable est aussi utilisée pour faire le lien entre deux parties de phrase ou deux phrases décrivant les précipitations.

• **type**: donne le type de précipitations.

• **action**: donne le type d'action décrivant l'évolution des précipitations. Par exemple, cette variable permet de décrire les changements de type de précipitations, ou le début et la fin des précipitations.

• **quantité**: donne la quantité de précipitations, telle que fournie par le modèle moteur. Cette variable est utilisée pour décrire les accumulations de précipitations supérieures à un certain seuil prédéterminé.

• **probabilités**: donne les probabilités de précipitations, telles que fournies par les prévisions statistiques. Cette variable permet de décrire les probabilités de précipitations pour les périodes de douze heures concernées.

Il n'y a pas de variable désignant explicitement l'accompagnateur dans le chaîne décrite plus haut. L'accompagnateur est implicite au type de précipitations. Si l'accompagnateur ne peut être adéquatement décrit par le type de précipitations, il déclenche un repliement supplémentaire de la chaîne, de façon à apparaître explicitement dans le texte.

La séquence de variables dans la chaîne s'apparente à la syntaxe normale du langage: sujet, verbe, complément. Cependant, le sujet peut devenir complément dépendant du type d'action choisi, et des règles doivent être prévues pour placer les mots correctement dans les phrases. Des règles doivent aussi être prévues pour assurer le respect de la grammaire de la langue utilisée. Le vecteur contenant les variables doit être initialé à zéro. Lorsqu'une des variables est mise à zéro, le module d'écriture ne prend alors aucune action et passe à la variable suivante.

Les règles de la base de connaissance utilisées pour prendre les décisions concernant la description de l'état du ciel et des précipitations, tiennent toujours compte des éléments prévus dans les douze heures précédant et suivant, la période d'intérêt. La matrice d'éléments doit donc contenir les prévisions des éléments du temps sous forme digitale entre zéro et 84 heures, pour décrire le temps jusqu'au jour 3 inclusivement. Ceci permet d'assurer la conformité entre les différentes périodes temporelles. De plus, la description de l'état du ciel tient compte de la description des précipitations, et vice-versa. Ceci assure donc la conformité entre les deux éléments. Enfin, des règles sont prévues pour déterminer un type de précipitations global, à partir des types qui sont trouvés à chaque trois heures dans la matrice d'éléments.

Les règles de la base de connaissance sont inter-reliées, et le programme moteur les interroge par chaînage avant. Lorsque le programme moteur trouve une règle qui s'applique à la

situation donnée, il procède plus avant en interrogeant les règles qui lui sont reliées. Les règles peuvent donc être considérées comme les branches d'un arbre. Chaque règle origine d'un noeud, et conduit à un autre noeud ou à l'extrémité d'une branche. Lorsque le programme moteur arrive à l'extrémité d'une branche, l'information est complète, et le module d'écriture entre alors en action. Toutes les règles qui ont leur origine au même noeud, sont exclusives et exhaustives. Toutes les possibilités sont donc considérées à chaque noeud, et il y a toujours une action à prendre par défaut, après avoir rejeté tous les autres choix possibles.

Il existe aussi deux autres types de règles. Il y a des règles dites d'explicitation, qui permettent d'attribuer une valeur à une variable dans la chaîne, sans avancer dans l'arbre de la base de connaissance. Il y a aussi des règles dites de généralité. Ces règles sont appelées par d'autres règles, et sont conçues de façon à éviter des répétitions.

Des valeurs sont attribuées aux variables de la chaîne à mesure que le programme moteur interroge les règles de la base de connaissance. Chaque valeur est un code numérique qui détermine le mot ou l'expression à utiliser lors de l'écriture des phrases. Les mots et les expressions sont répertoriés dans un dictionnaire français et anglais. Le module d'écriture place les mots ou les expressions les uns à la suite des autres, en obéissant aux règles sur la syntaxe. Un code particulier attribué à la variable "lien" indique au module d'écriture que la description de la nébulosité et des précipitations est terminée.

De façon à limiter le nombre de possibilités combinatoires, le système RAPELS ne peut décrire plus de deux actions à l'intérieur d'une même période de douze heures. Par exemple, les précipitations peuvent débuter et cesser à l'intérieur d'une période de douze heures, mais ne peuvent pas débuter, changer de phase et cesser pendant cette même période. Le système RAPELS fait donc un choix, et tente de décrire les situations complexes le plus justement possible.

Les quantités de précipitations sont décrites seulement si elles sont prévues comme étant supérieures à un certain seuil prédéterminé. Ce seuil est différent pour les précipitations solides et liquides. Les quantités de précipitations sont exprimées en cm si les précipitations sont solides, et en mm si elles sont liquides. Le module d'écriture choisit parmi des phrases complètes, et n'a qu'à insérer les quantités aux bons endroits.

Les probabilités de précipitations sont toujours placées à la fin des prévisions pour chaque période de douze heures. Encore ici, le module d'écriture n'a qu'à insérer les valeurs aux bons endroits, dans une phrase complète.

Une approche semblable est utilisée pour décrire les régimes de vents et de températures.

4.0 EXEMPLE.

Voici une exemple de prévision rédigée par RAPELS pour Iqaluit, à partir des données du 5 mai 1989, 00 TU. Le texte de la prévision est présenté en français et en anglais.

Iqaluit - prévisions préparées à 00 TU le 5 mai 1989.
AUJOURD'HUI.. NUAGEUX. POSSIBILITE DE QUELQUES AVERSES DE NEIGE EN APRES-MIDI. VENTS DE L'OUEST A 15 KM/H. MAXIMUM PRES DE MOINS 4. PROBABILITE DE PRECIPITATIONS 45 POUR CENT. CE SOIR ET LA NUIT PROCHAINE.. DEGAGE. VENTS DU NORD-OUEST A 20 KM/H. MINIMUM PRES DE MOINS 15. PROBABILITE DE PRECIPITATIONS 30 POUR CENT.

SAMEDI.. ENSOLEILLE. VENTS DU NORD-OUEST A 15 KM/H, RETROGRESSANT AU SUD-EST EN APRES-MIDI.
TEMPERATURES STATIONNAIRES PRES DE MOINS 11.
PROBABILITE DE PRECIPITATIONS ZERO POUR CENT.

SAMEDI SOIR ET LA NUIT SUIVANTE.. NEBULOSITE CROISSANTE EN SOIREE, GENERALEMENT NUAGEUX PENDANT LA NUIT. POSSIBILITE DE QUELQUES FLOCONS TARD LA NUIT. VENTS MODERES PAR MOMENTS. TEMPERATURES PRES DE MOINS 9 EN SOIREE, A LA HAUSSE POUR ATTEINDRE MOINS 3 TARD LA NUIT.
PROBABILITE DE PRECIPITATIONS 30 POUR CENT.

DIMANCHE.. NUAGEUX. QUELQUES AVERSES DE NEIGE EN APRES-MIDI. VENTS MODERES PAR MOMENTS. MAXIMUM PRES DE ZERO.
PROBABILITE DE PRECIPITATIONS 55 POUR CENT.

TODAY.. CLOUDY. CHANCE OF A FEW SNOW SHOWERS IN THE AFTERNOON. WEST WINDS AT 15 KM/H. HIGHS NEAR MINUS 4.
PROBABILITY OF PRECIPITATION 45 PERCENT.

TONIGHT.. CLEAR. NORTH-WEST WINDS AT 20 KM/H. LOWS NEAR MINUS 15.
PROBABILITY OF PRECIPITATION 30 PERCENT.

SATURDAY.. SUNNY. NORTH-WEST WINDS AT 15 KM/H, BACKING TO SOUTH-EAST IN THE AFTERNOON. TEMPERATURES STEADY NEAR MINUS 11.
PROBABILITY OF PRECIPITATION ZERO PERCENT.

SATURNAY NIGHT.. INCREASING CLOUDINESS IN THE EVENING, MOSTLY CLOUDY OVERNIGHT. CHANCE OF A FEW SNOWFLURRIES LATE OVERNIGHT. WINDS MODERATE AT TIMES. TEMPERATURES NEAR MINUS 9 IN THE EVENING RISING TO REACH MINUS 3 LATE OVERNIGHT.
PROBABILITY OF PRECIPITATION 30 PERCENT.

SUNDAY.. CLOUDY. A FEW SNOW SHOWERS IN THE AFTERNOON. WINDS MODERATE AT TIMES. HIGHS NEAR ZERO.
PROBABILITY OF PRECIPITATION 55 PERCENT.

5.0 CONCLUSIONS.

Sans nécessairement répondre à tous les critères définissant les systèmes experts et l'intelligence artificielle, RAPELS relève de l'intelligence artificielle. En effet, RAPELS permet de reproduire un processus qui relève de l'intelligence humaine, c'est-à-dire la sélection de mots pour la construction de phrases intelligibles. RAPELS s'adresse à un problème précis, dans un domaine restreint, dont toutes les variables sont connues: la composition de prévisions météorologiques pour le public.

Le système est composé d'une base de connaissance constituée de règles heuristiques, et d'un moteur qui permet d'explorer la base de connaissance. De plus le système RAPELS a été conçu pour donner une certaine forme d'explication sur le raisonnement effectué. Le système peut donner la liste des règles qui ont été vérifiées comme vraies, et les données qui ont été utilisées dans l'application de ces règles.

Les résultats présentés ici, ont été obtenus avec un investissement minimal en personnel et en ressource informatique. Un énorme travail reste encore à accomplir dans le domaine de la rédaction automatisée de prévisions en langage structuré. Cependant, compte tenu des ressources investies, les résultats présentés ici sont très encourageants.

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Strategies for the Development and Presentation of Operational Statistical Guidance Products in a Workstation Environment

by

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ABSTRACT

Recent experience in graphical displays and manipulation of statistical weather element products is described. Some current strategies for the presentation and manipulation of point-specific forecast guidance on workstations are discussed, and the paper concludes with our view of future trends in statistical technique development and implementation that are driven by rapidly advancing workstation technology.

RÉSUMÉ

Cet article décrit des expériences récentes de présentation graphique et de manipulation des prévisions météorologiques par des méthodes statistiques. Quelques stratégies de présentation de prévisions locales sur écran de station de travail sont discutées. L'article se termine avec nos vues sur les tendances actuelles en matière de développement de techniques statistiques et sur l'influence grandissante des ordinateurs et des stations de travail.

1. INTRODUCTION

Currently, nearly all statistical guidance products available to forecasters in regional offices are prepared and issued from the Canadian Meteorological Centre (CMC). They make heavy use of the operational model output and are run after the model forecasts have been completed. The statistical products are transmitted to regional offices in the form of tables of numbers, with one or more tables prepared for each station. Forecasts of some elements are available for more than 250 stations, each 12 hour cycle.

As statistical guidance products become more numerous, the volume of the numerical output produced will also increase. (Two new products, marine surface winds and probability of precipitation type have recently been introduced, for example) Assimilation of numerical forecasts in tabular form is difficult for the human, and we have been told on many occasions that statistical guidance might be regarded as more useful if presented in graphical form. The fact that some regional offices have developed their own display programs for the tabular output issued from CMC supports this view. Increasing the volume of output only makes it more important that alternative display methods be explored.

Some recent experiments in alternative methods of displaying statistical guidance products have been carried out in MSRB. These experiments have been associated with development of region-specific forecast techniques. Four such projects have been undertaken in the last four years: 1. CASP experimental forecasts of spot temperature, precipitation type, cloudiness, wind, ceiling and visibility; 2. Calgary Winter Olympics forecasts of temperature and wind for 8 olympic sites; 3. Southern Ontario snowsquall forecasts; and 4. Statistical guidance for forecasting Pacific marine "bombs". Alternative display methods were an important component of the first two of these projects.

The weather element forecast techniques development group in MSRB has also developed a Classical-REEP method for very short range forecasting (Wilson and Sarrazin, 1989). Since this technique does not require model output, it is easy to design to operate on a regional microcomputer or workstation. The design of the user interface for this method is an example of the use of a microcomputer for the control of statistical guidance products.

It is still difficult to follow up on these experiments because regional offices have not generally had the technology to implement them. However, as workstations become more common, many changes can and should be made in the way statistical guidance products are processed and distributed.

This paper explores the possibilities for improving the development and display of statistical guidance products. Beginning with a brief summary of the initial experiments, it continues with a description of current activities and plans, and concludes with a look to the future.

2. SUMMARY OF EXPERIENCE

2.1 Displays for the Calgary Olympics

Using special datasets collected the three winters prior to the 1988 Calgary Winter Olympic Games, forecast equations were prepared for surface winds and temperature at eight different locations around the olympic sites. The forecasts were in model output statistics (MOS) format and were valid for 09, 11, 13, 15 and 17 local time for the first and second day. They were driven by the operational spectral model. The goal of this project was to determine the ability of the MOS forecasts to distinguish local scale variations while driven from a synoptic scale model. For the Olympic forecast office, it provided a convenient way of incorporating the climatology from the special observation sets into the daily forecast.

In operation, the forecasts were run at CMC and transmitted to the Olympic office in Calgary, where they were displayed on a microcomputer. The display consisted of a colour map of the olympic sites, with the forecast information shown in numeric form at the appropriate locations on the map. The valid time of the information could be selected from a menu in the upper right corner of the display.

In addition to the special winds and temperature forecasts, national scale products were available on the display system. These consisted of forecasts of MOS wind direction and speed, perfect prog probability of precipitation and cloudiness, and MOS ceiling and visibility, valid at 6 hour intervals to 48 hours. The POP forecasts were presented as numeric values for each station plotted on a map, the winds were presented as normal wind barbs plotted on a map with the forecast MSL pressure, and all the others were presented as probability forecasts. For probability forecasts, histograms were plotted at station sites, with the suggested "most likely" category coloured differently from the other categories. The displays were available in two or three levels of zooming, depending on the product. The total station set for the national scale products consisted of 42 stations over western Canada.

The displays were well-received by the forecasters in the Olympic office. Since the Olympics ran for only 2 weeks, there wasn't enough data available to evaluate the quality of the forecasts. This experience suggests that statistical products are more likely to be used if they are presented in mapped form.

2.2 SHORT

SHORT is a classical very short range forecast procedure that is designed as a convenient way of processing station-specific climatological information. Given the current and last observation, it calculates probabilities of occurrence of categories of weather elements, and selects the "best" forecast category of each element comparing the forecast probabilities with climatological frequencies. In the latest version of the program, both the probabilities and the selected forecast category are available at the discretion of the user. Backed by 30 years of observations of hourly weather for each station, the system can best be regarded as a guide to the climatology of trends in the weather and can be used as a check on the reasonableness of forecast weather sequences, especially in terminal forecasts.

SHORT has been available in some regional offices for three years or so. Since it does not require model output data or any other data from external sources to run, it is relatively easy to set up a user interface

program to run in a forecast office. Earliest versions of SHORT were designed to run on the HP 1000 computer, but the most recent version has been designed to run on a microcomputer. This version was developed following a request from Central Region. Figure 1 shows an example of the input screen and the output screen. Program control is by means of the menu shown at the bottom of the input screen. Two additional output screens are available which show the forecast probabilities.

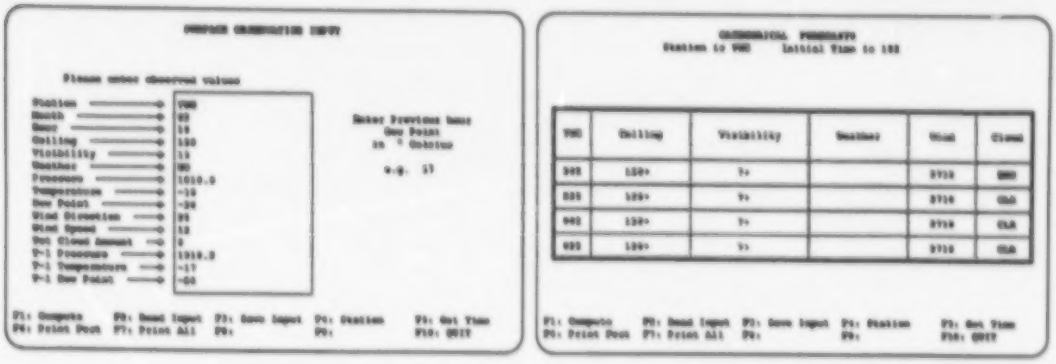

Figure 1. Input screen (left) and output screen (right) for the current version of the short range forecast guidance program "SHORT". Program control is via menu at bottom of screen. Data is entered by hand but can be saved for later editing.

Applicability of this program in operations is limited at present by the need to input the observation data by hand. Also, it is a little ahead of its time: It is not yet being used by the region for which it was designed because they do not have PCs in the forecast area. (Brad Shannon, personal communication). Once workstations are available and are linked to the data communication system, both these problems can be resolved.

SHORT is an example of the use of statistical processing and user interface programs to provide flexible and easily accessible guidance for short range trends in the weather. For maximum utility, it awaits better real time data access and a microcompter or workstation environment.

3. CURRENT ACTIVITIES

3.1 Statistical Products and the FPA

The core of the forecast production assistant (FPA) is a graphical editing system which allows a forecaster to prepare a horizontal weather depiction chart on a workstation. The system allows editing of NWP forecast fields as well as the addition of weather parameters in the form of an areal depiction. The information entered on the depiction chart is then interpolated in time to produce a sequence of charts for use in production of text forecasts.

One design limitation that has been recognized is that statistical products which are driven from NWP model output and which produce weather element forecasts for points are not easily included in a consistent fashion. There are two aspects to the problem: First, if the NWP fields can be modified, it is necessary to ensure that the statistical products can be modified so that they are consistent with the modified NWP output. Secondly, the display and editing capabilities of the system will need to be extended to include the display and manipulation of point-specific forecasts.

A project is currently underway to address these problems. Since the FPA is targetted toward the marine FP, and already includes a simple wind forecasting method, we are starting with this element. A simple

surface wind forecasting technique will be developed which uses only the MSL pressure field, under the assumption that the MSL pressure is the most likely model output field to be modified by the forecaster. We will then do an experiment to compare forecasts using the simple equations with perfect (analysis) data with forecasts using equations based on the full model output in forecast mode. This type of comparison is intended to determine whether forecaster-modified fields (represented by the perfect forecasts) can improve on the original model-driven forecasts even when the predictor set is limited. This experiment is being directed at surface winds because of their importance in marine forecasting and because of their close link to the MSL pressure field.

Other weather elements will have to be treated differently. For example, precipitation (POP) is driven more by middle atmosphere processes. We haven't thought of a direct way of matching the forecaster's precipitation depiction with POP forecasts from the model. The best route in this case might be to present the POP forecasts as guidance, contoured like the model output, and to extend the graphics editor to permit editing of the POP forecasts directly. Thus the forecaster would be responsible for ensuring that the POP guidance from the model is changed consistently with whatever changes were made to the other model forecasts, and the FPA would be limited in this case to tools to assist in this process. Questions like this will have to be answered when the FPA is targetted towards the public forecast since POP is a public forecast parameter.

Some elements might be best displayed as numeric values at points. Statistical products usually incorporate local climatological effects for each station, which would tend to be lost if the forecasts are contoured before presentation on a workstation. A good example is surface winds for land stations. To the extent that these are influenced by valley effects, local circulations such as sea breezes etc., information will be lost if contouring is done. For such elements, the graphics editor could be extended to permit editing of point values, and the interpolation process could be extended to permit interpolation of point values in time, that is, generation of a trend sheet for a point. Maybe it will be necessary to have a completely different "assistant" for entering local variability into forecasts.

The FPA is an example of the use of workstation technology to assist forecasters in the process of inputting the meterology into forecasts. It will be a significant challenge to the design to include both synoptic and subsynoptic information, and to ensure that sufficient editing capability is available for guidance tools that are used for each target forecast type.

3.2 Local Blended Guidance - An idea whose time has come

The idea of updating objective guidance products with the addition of more recent information and/or the addition of small scale forcing is not new. In the U.S. for example, a local update system for their MOS forecasts has been under development for about 10 years (LAMP - Glahn and Unger, 1986). Systems such as LAMP are designed to permit objective updating of the model output, controlled locally. Updating systems are most useful for short range forecasting in the first 24 hours. They also have the advantage of being controlled regionally; forecasts can be initiated when needed as guidance for a particular operational product, and the latest available information can be considered.

Workstations should aid the process of managing and running an update system in regional offices. With this in mind, we have begun working on an updating system targetted toward the terminal forecast (FT). Called LBG for Local Blended Guidance, it is shown schematically in Figure 2. Figure 2 represents a framework for a blending system; there is considerable flexibility in the design. The intention is to separate the components that can be constant and are based on large datasets (national statistical guidance and classical forecasts) from the components that will need more frequent updating and which may be based on smaller datasets. The former would in all likelihood imply central development using very large centrally available datasets, while the latter (the blending equations) might be developed either centrally or regionally depending on available resources and interest. The possibility also exists to incorporate existing products (CMC statistical guidance products, for example), as long as they are not perishable.

Unlike the LAMP system, this design does not include "local models". The reason for this is that their inclusion greatly increases the complexity of the system, and decreases the flexibility of the design because one has to consider local analysis programs, and greater computational power. Furthermore the results from LAMP show important contributions from the simple models for only a 4 hour window from about 4 hours to 8 hours. (Unger, personal communication). The complexity of the LAMP system is a disadvantage in our view, and may have contributed to delays in making it operational. If it becomes feasible and worthwhile, local models could be added later.

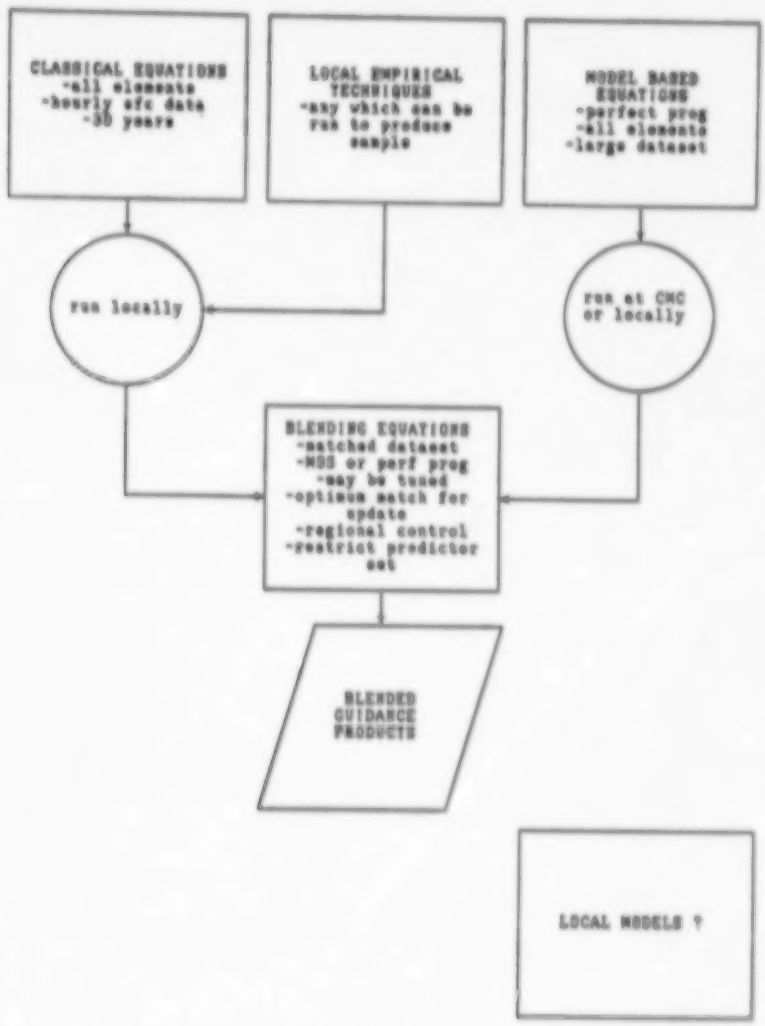

Figure 2. Schematic representation of a blended local guidance system. The system takes forecasts of weather elements from many sources and applies statistical or expert system procedures to blend them into an improved guidance product.

The blending equations may take many forms. One possibility is to do statistical processing on a sample of forecasts generated by running the classical, model-dependent, and local empirical methods on a matched sample of sufficient size (probably 2 years or more). Otherwise, if each method produces forecasts of the same weather element, a rule-based system could be built to select the best or combine the individual forecasts. If new fine scale NWP models become available, special predictors or the direct weather element forecast output from these models could be entered into the blending system as soon as enough of it is

available. Furthermore, the blending system could be designed to be self-updating where recent predictor information is weighted more than older information, following the ideas of Ross (1989). There are many possibilities for such a system and considerable flexibility to tune it to the schedule and specific requirements for each office which will use it.

Although not shown on the diagram, it is intended that the separate inputs of the blended model would be available as guidance products separately. To the extent that the blended model is a derived guidance product, its interpretation as guidance becomes more difficult, and access to the component inputs will help in the same way that access to model output fields helps in understanding derived model output products.

Finally, the output of LBG is guidance, not a final product. As such, it might be one of many inputs to a graphics editor and/or text composition program such as the FPA. It will be of most use for the first 24 hours, but integration with national model-based guidance products for the second 24 hours is necessary. For example, for the second 24 hours, the same framework would be used, but the blending might be limited to direct model output and statistical products, all driven by the current operational NWP model. If and when CMC takes over responsibility for day 2 forecasts, the output of the blended forecasts would be fed to an automated forecast composition program at CMC. Until then, it would be transmitted as guidance, or, the model output would be transmitted to regions and the blending would be done under regional control.

4. FUTURE

We conclude with a few general comments about our views of the future development and operation of statistical guidance products with the evolution of workstation technology. First of all, it will get easier to pass data around. Recent developments in compact high capacity mass storage devices such as rewriteable optical disks and small high capacity tape systems make it possible to deal with the data handling problems of statistical development without using mainframes. In fact, it is now possible to carry out the statistical development required for a set of national guidance products with an investment of about $40000 in hardware and software. Elapsed time to do the development would not likely be greater than what can be achieved on a mainframe. As a result, it becomes easier to turn over development of statistical products to interested regional staff. The implication is that the role of central technique development groups will turn more toward active consultation. Furthermore, it becomes easier to accommodate regional variations in product design throughout the process.

Secondly, there is likely to be a tendency for CMC to move away from transmission of finished graphical products toward transmission of digital data. Workstation technology makes it easier for the graphics to be done regionally, and, the communication requirements for digital model data are not large compared to image data. Again, regional differences in formats can be easily accommodated this way. The implication is that guidance products may eventually all be produced regionally, even if the technique development is done centrally.

Thirdly, the proliferation of guidance of various types will probably continue, increasing the pressure for objective methods to help with assimilation of this information. Statistical blending and rule-based or expert systems are two examples of these. The former use historical data as the "expert" while the latter use human experts to define the rules. We see a continued increase in development activity in these areas.

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VISUALISATION ET TRAITEMENT DES DONNEES METEOROLOGIQUES A LA DIRECTION DE LA METEOROLOGIE NATIONALE : LE SYSTEME METEOTEL.

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RESUME

La nécessité de fournir opérationnellement des données météorologiques classiques ou télédétectées à tous les centres de son réseau a conduit la Direction de la Météorologie Nationale (DMN) à développer depuis 1984 un système original de transmission et de visualisation d'images : METEOTEL. Ce système fiable et simple d'utilisation, offrant une grande variété de produits de qualité et des fonctions spécifiques, s'est imposé comme un outil d'aide à la prévision, aussi bien pour les météorologistes que pour de nombreux usagers professionnels. Il ne constitue qu'une étape initiale en matière de systèmes opérationnels, la DMN entreprenant de nouveaux projets intégrant les dernières technologies et standards de l'environnement micro-informatique.

In order to provide operationally teledetected or conventional data to all its centres the French Weather Service has carried out since 1984 the development of METEOTEL, a proprietary system designed to disseminate and to display meteorological images. This reliable and easy-to-use system which proposes a large variety of elaborated products and specific features represents now an indispensable aid to forecasting, as well for the meteorologists as for a lot of professional users. After this first experience in the field of operational systems, new projects integrating the update micro-computer technologies and standards are already in development.

INTRODUCTION

Il y a moins de dix ans, les messages et les documents cartographiques ou photographiques sur papier étaient en pratique les principaux supports de travail d'exploitation en France, et certainement dans la plupart des pays. Les échos radar, par exemple, n'étaient disponibles visuellement que sur le scope du radar lui-même. Aujourd'hui, tous les prévisionnistes disposent sur écran, de manière automatique et continue, non seulement des images radar et satellite, mais aussi d'autres données, comme les produits de modèles numériques.

Pour la DMN, la possibilité de fournir régulièrement des données météorologiques sous forme d'imagerie numérisée nécessitait la création d'un matériel de visualisation et de traitement répondant a ses besoins : équiper toutes les stations françaises avec un système adapté au travail du prévisionniste. Les impératifs d'alors - une mise en oeuvre rapide, un rapport fiabilité/prix performant et une intégration dans l'opérationnel préexistant - ont produit la console METEOTEL.

Entièrement développée par la DMN, elle sert de terminal à un système de diffusion d'images et est équipée de fonctions de visualisation spécifiques. Ce système fonctionne actuellement sur 300 sites environ, dont 150 centres météorologiques. La DMN a mis en place un ensemble de services d'abonnement et d'assistance à l'intention des organismes et entreprises qui utilisent METEOTEL comme système de signalisation des intempéries et de prévision à très courte échéance pour optimiser leurs activités liées au temps.

LE SYSTEME METEOTEL

1. - Le terminal

METEOTEL est donc un terminal professionnel destiné à recevoir, stocker et visualiser en couleur des images météorologiques sur un moniteur de télévision. L'unité de traitement est basé sur le micro-processeur INTEL 8088, utilise un clavier spécialisé et un poste TV au standard SECAM/PAL relié par câble PERITEL. Une imprimante graphique, un lecteur/enregistreur de cassettes et un micro-ordinateur compatible PC peuvent également servir de périphériques.

Le logiciel METEOTEL, écrit en assembleur, gère une mémoire allant de 1 Mo (28 images de 32 Ko) à 8 Mo (256 images). La carte vidéo MATROX RGB 64-4 permet de mémoriser et d'afficher une image avec une résolution de 512 x 512 pixels en 16 couleurs.

La réception des images se fait en mode synchrone à 4800 b/s.

2. - Le système général d'information

Un des aspects intéressants du système METEOTEL est le rassemblement sur une seule console de plusieurs types d'information qui représentent les diverses formes d'alimentation en données météorologiques : réseau OMM d'observation au sol, satellite météorologique, réseau radar, réseau de localisation de foudre, modèles numériques.

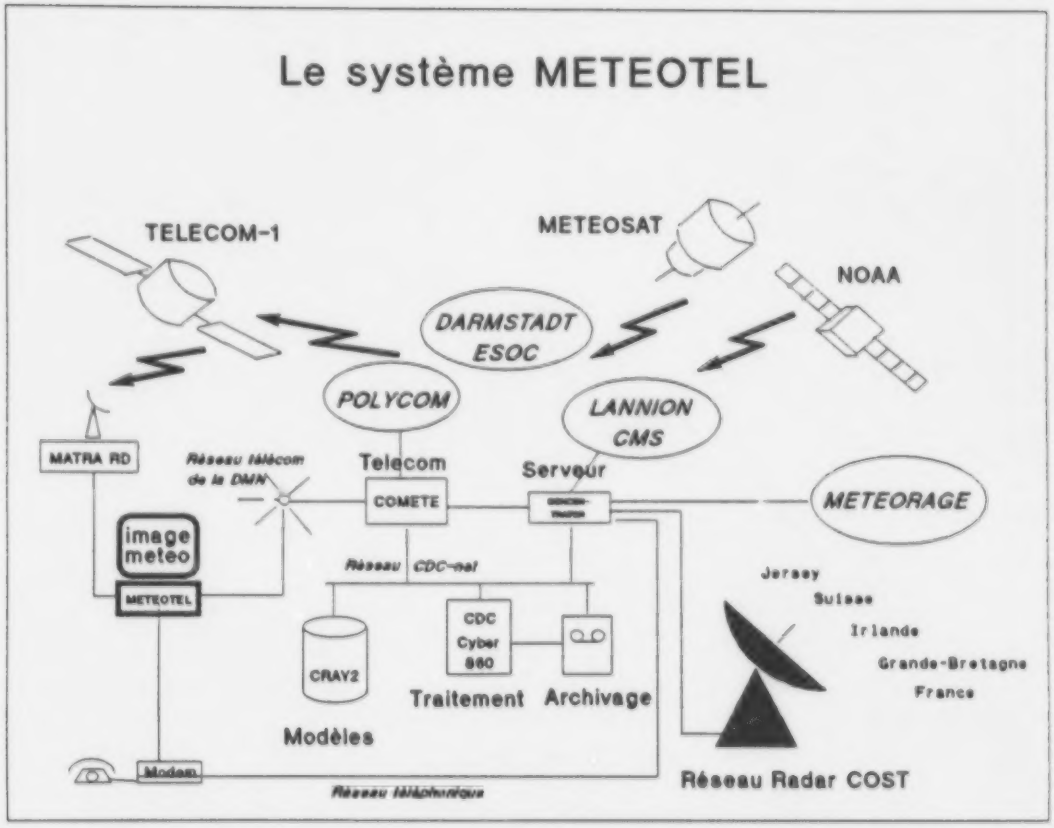
Le traitement des données parvenant jusqu'à chaque METEOTEL utilise les principaux calculateurs de la DMN. Le coeur du système est cependant le concentrateur, possédant également des fonctions de traitement et de serveur, localisé au Service Central à Paris (SCEM). Outre la concentration et le contrôle des données radar et satellite, ce calculateur ultra-spécialisé réalise en temps réel la fabrication de l'image composite radar et fonctionne comme serveur de l'ensemble des images du système, en liaison avec le calculateur des télécommunications (COMETE).

La figure présente en raccourci les composantes du système METEOTEL, organismes intervenant et moyens de traitement et de transmission mis en oeuvre.

3. - La connexion aux réseaux

A partir du concentrateur, la diffusion des images peut emprunter trois voies :

- **le réseau en étoile de la DMN**, constitué de lignes spécialisées à 4800 b/s, il rayonne du calculateur COMETE et délivre un programme d'images aux divers centres et stations françaises ou étrangères ainsi qu'aux clients abonnés; ce réseau convient à des besoins importants et de longue durée.



Cette figure schématise les principales composantes du système METEOTEL : sources d'information, réseaux, calculateurs et organismes participants.

- **le réseau téléphonique commuté (RTC)** qui permet d'accéder à la banque d'images du serveur via un modem synchrone à 1200 b/s; l'accès au serveur est protégé par un code client; ce mode de connexion convient à des besoins ponctuels; il sert aussi à l'exploitation de l'imagerie radar.

- **le satellite TELECOM-1**, utilisé opérationnellement depuis 1989 pour des liaisons à 4800 b/s (9600 b/s ultérieurement), il s'inscrit dans un plan global de télécommunications de la DMN; adaptée à la réception mobile, cette réception permet une souplesse de configuration du réseau.

LE SERVICE METEOTEL

METEOTEL fournit des informations météorologiques, rapatriées sur le concentrateur serveur, puis transmises sous forme d'images. La visualisation de ces images par fonctions préprogrammées, adapté aux impératifs de l'opérationnel, permet une compréhension rapide et détaillée de la situation météorologique.

1. Les images

- L'imagerie radar

METEOTEL fournit les données des réseaux radar français (onze radars en 1989), suisse, irlandais et britannique rassemblées en une image composite sur un domaine de 1500 x 1500 km autour de la France, et renouvelée toutes les 15 minutes. Les images des radars individuels s'obtiennent par connexion directe ou par interrogation du serveur sur le réseau RTC.

- L'imagerie issue des satellites

Les images infrarouge et visible de METEOSAT traitées au Centre de Météorologie Spatiale de Lannion sur le domaine France (toutes les 30 minutes et sur un domaine étendu (toutes les 3 heures) constituent la deuxième grande source d'information. Cette imagerie associée à l'information radar sur la France est mise en valeur par des fonctions de type "Rainsat" ou d'écrémage des niveaux de couleurs. Les données du satellite polaire TIROS de la NOAA sont traitées pour fournir des images de classification nuageuse sur la France.

- Le réseau de base OMM

Les observations synoptiques ou destinées à l'aéronautique de 340 stations en Europe, sont extraites de la Banque de données météorologiques de la DMN, puis traitées pour constituer une information comprimée. Les paramètres météorologiques sont affichées en incrustation sur les autres types d'image, aux emplacements des stations. Cette information est renouvelée toutes les heures avec un délai de 15 minutes par rapport à l'heure des observations.

- L'information graphique digitalisée.

Elle consiste en deux cartes (analyse et prévision à échéance de 12 heures) élaborées par la Prévision pour la Sécurité Routière. Les phénomènes météorologiques susceptibles d'influer sur la circulation automobile sont signalés sur la France par des symboles prédéfinis. La saisie des cartes est semi-automatique sur un terminal graphique SECAPA et le traitement s'effectue sur le mainframe opérationnel. La diffusion biquotidienne a lieu en fin de nuit et d'après-midi.

- L'information METEORAGE.

Les données du réseau de localisation d'impact de foudre exploité par la société METEORAGE FRANKLIN sont visualisables toutes les 15 minutes. La concentration des mesures via le réseau TRANSPAC, son traitement par un système temps réel et transmission au serveur par ligne spécialisée assurent la disponibilité de cette information en quelques secondes.

- Les images climatologiques.

Les données hydrologiques peuvent être traitées comme des images et revisualisées sur METEOTEL. De la même manière les images radar et satellite archivées.

- L'imagerie issue des modèles numériques.

La visualisation sur plusieurs échéances de certains champs prévus sur la France est l'un des produits les plus utilisés par les prévisionnistes. Le modèle numérique utilisé est PERIDOT, à maille fine sur la France dont on utilise une sélection de champs tels que le vent, l'humidité, la nébulosité ou la température pseudo-adiabatique. L'intérêt de cette information réside dans la possibilité de coupe de l'atmosphère et d'animation des champs prévus. Ce type d'imagerie semble celle qui bénéficiera le plus de développements dans les futurs systèmes de visualisation.

2. Les fonctions

Comme tous les systèmes actuels de fourniture d'information digitalisée, METEOTEL propose les fonctions de visualisation courantes qui facilitent les tâches d'exploitation et mettent en valeur les phénomènes météorologiques importants.

Parmi les principales fonctions accessibles :

- LOCALISATION d'un pixel et indication de sa valeur
- ZOOM sur une zone sélectionnée
- ANIMATION d'une série temporelle d'images de même type
- SUPERPOSITION d'information radar sur satellite et inversement
- CALCUL DE VITESSE de déplacement de zone (radar, satellite)
- EXTRAPOLATION de position avec la vitesse calculée
- BISSEUILLAGE sur les images satellite
- ADVECTION d'une image par un champ de vent de PERIDOT ...

LA PHILOSOPHIE METEOTEL

L'évolution sur cinq ans de METEOTEL axée sur la mise à la disposition aux usagers de produits fiables et directement utilisables peut se caractériser par les concepts suivants :

- système d'information météo destiné à l'opérationnel
- utilisation des dernières techniques de télécommunications
- importance de la protection des informations
- concentration des informations vers un serveur fiable
- assistance météorologique par le service météo national ...

Pour la DMN le système METEOTEL, mis en oeuvre avant l'essor et la standardisation de la micro-informatique, ne constitue que la première étape dans le développement des systèmes d'information météo.

Le récent projet AEROMET, qui vise à produire les mêmes services complétés par d'autres produits sur un terminal micro-informatique compatible PC intégrant les fonctions de télécommunications via le réseau téléphonique commuté (modem MINITEL) et offrant de meilleures possibilités d'imagerie et de graphique, va élargir le public d'utilisateurs d'informations météo équipés en matériel standard.

L'étape suivante est la mise en oeuvre du projet SYNERGIE d'un système complet dédié au travail de la prévision météo, incluant réseaux, stations de travail, serveurs et utilisant les derniers perfectionnements informatiques en matière de graphique et d'imagerie.

SYNERGIE - UNE STATION DE TRAVAIL POUR LE PREVISIONNISTE A LA DIRECTION DE LA METEOROLOGIE NATIONALE

Jean Coiffier
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RESUME

Le but du projet SYNERGIE est de doter les services de prévision nationaux et régionaux de stations de travail interactives destinées à permettre aux prévisionnistes de profiter pleinement de la richesse des informations qui leur sont fournies. Après avoir passé en revue les diverses fonctions d'une telle station de travail, on explique la stratégie qui a été adoptée pour mener à bien un tel projet : choix d'une configuation matérielle de base, sélection d'applications pilotes qui doivent être testées de façon opérationnelle, étroite association des prévisionnistes à la définition des fonctions de leur station de travail.

The aim of the SYNERGIE project consists in providing the national and regional forecasting services with interactive workstations allowing forecasters to get as much benefit as possible from the huge amount of information they have do deal with. After going through the various functions of such a tool, we explain the main ideas of our strategy to achieve this challenge : choice of a hardware configuration, selection of meteorological applications which must be operationally tested, close cooperation with forecasters to define the functions of their workstation.

INTRODUCTION

Au cours de ces dernières années le travail du prévisionniste s'est trouvé profondément modifié en raison des innovations techniques qui ont entrainé un accroissement considérable du flux d'information disponible : l'observation traditionnelle se trouve désormais complétée par une panoplie d'images issues de diverses sources (radars, satellites, etc.) et les modèles de prévision numérique fournissent une description de plus en plus détaillée de l'atmosphère.

Cependant le prévisionniste n'utilise qu'une faible partie de l'information disponible en raison de l'absence d'un outil adapté. Le but du projet SYNERGIE (SYstème Numérisé d'Exploitation Rationnelle et de Gestion Interactive et Evolutive des informations météorologiques pour le prévisionniste) est de mettre à la disposition des services de prévision nationaux et régionaux des stations de travail interactives destinées à aider les prévisionnistes dans leurs diverses tâches opérationnelles d'exploitation.

FONCTIONS DE LA STATION

Généralités

Avant d'examiner les diverses fonctions attendues d'une station de travail, il convient de formaliser les diverses tâches accomplies par le prévisionniste.

Le prévisionniste reçoit une grande quantité d'informations diverses : des messages, des cartes d'observations pointées, des cartes analysées ou prévues tracées sous forme d'isolignes, des documents fac-simile venant de centres étrangers, des images de sources variées (radars, satellites, réseaux de détection d'éclairs).

De façon générale le prévisionniste fournit des cartes analysées ou prévues à caractère technique, des cartes plus simplifiées décrivant le temps sensible. Il rédige également des messages de directives ainsi que des bulletins à l'intention du grand public. Une partie de ces documents est destinée à un usage interne alors qu'une autre partie est ciblée pour certains utilisateurs extérieurs particuliers (prévision générale, aéronautique, marine, journaux, radios et télévisions).

Les fonctions du prévisionniste peuvent donc se résumer ainsi : il s'informe, analyse méticuleusement les cartes, compare et interprète les divers documents et effectue une synthèse. Il founit ainsi une prévision concrétisée par la rédaction de divers messages et la réalisation de cartes plus ou moins spécialisées.

Fonctions graphiques

Il s'agit de visualiser, comparer et évaluer tous les champs fournis sur des grilles plus ou moins régulières comme les divers réseaux d'observations ainsi que les sorties des modèles de prévision numérique. On peut identifier un certain nombre de fonctions adaptées au traitement de ce type d'information :

- le pointage des observations avec possibilité de sélection partielle par zone ou sur un critère de seuil ;
- le tracé d'isolignes avec possibilité de lissage et d'impression de valeurs extrêmes ;
- La superposition de plusieurs champs incluant en cela les images satellitaires ;
- le calcul et le tracé de champs de différences ou de divers champs dérivés ;
- l'animation de ces divers champs pour suivre facilement l'évolution temporelle (avec éventuellement calcul de champs intermédiaires interpolés dans le temps) ;

- la possibilité de modifier de façon interactive les champs analysés ou prévus et de récupérer le résultat des modifications comme nouvelles valeurs en points de grille ;

- la possibilité de faire un balayage par coupes verticales sur tous les champs définis dans un volume 3D ;

- la visualisation des radiosondages observés ou prévus ;

- la visualisation de séries chronologiques sous forme de météogrammes ;

- le dessin assisté d'un certain nombre de symboles sur un fond de carte (tracé frontologique, tracé de symboles explicatifs sur les cartes aéronautiques, pictogrammes de description du temps sensible pour les divers media) ;

- la visualisation de valeurs de référence comme la climatologie et la possibilité de retrouver un certain nombre de situations caractéristiques correspondant à des évènements météorologiques particuliers ;

- La visualisation de documents graphiques venant de services météorologiques étrangers.

Fonctions imagerie

Ces fonctions doivent permettre la visualisation d'un certain nombre de champs qui ne se prêtent pas au tracé d'isolignes (images satellitaires ou radars) mais aussi d'offrir une solution alternative à la présentation graphique des sorties de modèles (zones colorées qui peuvent être superposées à des champs d'isolignes).

Il est donc nécessaire de pouvoir assurer :

- les fonctions élémentaires de zoom et de panoramique ;

- la superposition d'images ou d'images et de tracés sous forme d'isolignes ;

- la réalisation de séquences d'animation ;

- le coloriage entre contours soit sur une carte issue de la prévision numérique, soit sur des documents réalisés par le prévisionniste ;

- la superposition de fonds de cartes et de diverses trames sur les images;

- le changement de projection cartographique ;

- le seuillage des images, la modification facile d'échelle de couleur, de contraste ;

- la possibilité d'advection de certaines images en fonction de critères variés (vents issus de la prévision numérique par exemple) ;

Fonctions alphanumériques

Il est nécessaire de pouvoir sélectionner et visualiser facilement les messages reçus sous forme de textes et également de fournir une aide à la rédaction et à l'envoi de produits sous forme alphanumérique. Ainsi il doit être possible :

- de visualiser les messages correspondant à une zone donnée ;
- d'avoir accès à tous les bulletins d'une journée ;
- de rédiger rapidement les messages concernant la sécurité ;
- de reprendre une partie des messages émis antérieurement ;
- de rédiger un texte tout en visualisant d'autres produits graphiques.

L'acquisition et la diffusion des données

Les données nécessaires à l'alimentation de la station de travail sont disponibles au service central, localisées sur diverses banques de données. La station dispose également d'une mémoire de masse permettant de stocker l'essentiel de l'information qu'elle doit traiter. Cependant, il est fondamental d'aménager un système de transfert rapide, transparent pour l'utilisateur, des banques de données vers la station de travail de façon à ce que l'information non immédiatement disponible puisse être acquise sans délai.

Symétriquement tous les produits, textes alphanumériques ou cartes élaborés sur la station de travail SYNERGIE, doivent pouvoir être stockés sur place ou alimenter des banques de données élaborées et être acheminées vers les divers destinataires.

STRATEGIE

Le choix de standard

La réalisation de nombreux programmes d'applications météorologiques sur une station de travail représente un investissement important qu'il convient de rentabiliser au maximum en rendant le système aussi ouvert que possible. Afin de s'affranchir au maximum d'une configuration matérielle particulière ou de logiciels de base spécialisés il a été décidé de s'appuyer sur un certain nombre de logiciels standard :

- le système d'exploitation UNIX,
- les compilateurs C (éventuellement C++) et FORTRAN 77,
- le protocole TCP/IP pour le transfert de fichiers,

- le noyau graphique de base GKS,
- le multifenêtrage X-Windows pour l'interface usager.

Le logiciel graphique sélectionné pour le moment est MAGICS, produit développé au CEPMMT. Ce logiciel présente l'intérêt de remplir une bonne partie des fonctionnalités requises dans le cadre d'une exploitation météorologique et d'être désormais utilisé par plusieurs pays européens, ce qui devrait faciliter son enrichissement ultérieur.

En ce qui concerne le format de représentation des données destinées à alimenter la station de travail, il est fondamental là aussi d'adopter des standard reconnus. Ainsi les codes binaires préconisés par l'OMM, BUFR pour les observations et GRIB pour les champs en points de grille, ont été retenus. La possibilité d'utiliser ces codes pour transmettre et stocker les images radars ou satellitaires est à L'étude. Par ailleurs, les possibilités d'utilisation d'une base de données compatible avec le langage SQL sont également envisagées.

En ce qui concerne les formats d'échange, internes à la Météorologie ou vers l'extérieur, on pourra utiliser pour les gros fichiers graphiques le format CGM, déja répandu dans la communauté scientifique, et le format POSTCRIPT pour les documents élaborés alphanumériques et graphiques plutôt destinés à une impression de qualité ou à des clients extérieurs comme les medias. Les documents complexes échangés par télécopie, en particulier avec les centres étrangers pourront être codés en format T4.

La maquette

Avant d'équiper les services de prévision nationaux et régionaux en stations de travail il s'est avéré judicieux de commencer par développer, tant sur le plan matériel que logiciel, une maquette dont le but est de valider les choix effectués. Le matériel sélectionné consiste en une station TEKTRONIX XD88/30 dotée d'un processeur de 17 MIPS et d'un moteur graphique performant. La visualisation est effectuée sur un moniteur couleur haute résolution de 19 pouces (1280x1024 pixels). Une tablette à digitaliser, destinée à tester certaines applications graphiques, complète cet équipement.

Les applications pilotes

Cette station de travail doit permettre le développement d'un certain nombre d'applications pilotes, répondant en général à des besoins encore incomplètement satisfaits dans le cadre actuel de l'exploitation.

- la visualisation complète d'une échéance donnée d'un modèle: balayage par coupes 2D d'un volume 3D multiparamètres (géopotentiel, température et vent) ;

- l'animation de sorties de modèles numériques sur plusieurs échéances pour un certain nombre de champs sélectionnés ;

- la superposition d'images satellitaires et de divers champs issus de l'analyse objective ou de la prévision numérique ;

- la visualisation sélective d'observations, leur superposition avec les champs prévus et le marquage de celles qui s'écartent, au delà d'un certain seuil, de la prévision ;

- la conception assistée de la carte de surface corrigée par le prévisionniste (modification interactive de la position des centres d'action, de leur intensité, des gradients, tracé des fronts) ;

- La supervision de la prévision automatique de températures fournies par l'interprétation statistique (prévisions tri-horaires sur une quarantaine de villes du territoire national).

Ces applications doivent être testées de façon quasi-opérationnelle sur une station mise à disposition des prévisionnistes de façon à mettre en évidence les divers problèmes rencontrés. Il est particulièrement important d'évaluer les temps de réponse du système, l'ergonomie générale de la station et en particulier la convivialité de l'interface usager qui doit permettre un dialogue aisé entre l'homme et la machine.

PLANS POUR LE FUTUR

C'est au vu de l'expérimentation réalisée de façon quasi-opérationnelle sur la maquette que l'on pourra décider de figer les fonctions de la station de travail SYNERGIE et de définir de façon précise son interface usager. On envisage l'installation de stations de travail après le transfert dans le sud de la France à Toulouse, à l'automne 1991, des services techniques de la Direction de la Météorologie Nationale. D'ici là il faudra régler les problèmes généraux d'ergonomie (niveau de bruit, luminosité des écrans, disposition dans la salle) de façon à fournir un outil utilisable sans fatigue excessive par le prévisionniste.

Une partie des fonctionnalités de la station de travail devrait également pouvoir être utilisées dans des centres départementaux équipés de micro-ordinateurs, dont le rapport qualité/prix ne cesse de s'accroître.

Il est certain que l'utilisation d'un nouvel outil va profondément modifier la façon de travailler du prévisionniste. On peut s'attendre à ce que le bulletin traditionnel fourni par le prévisionniste évolue vers une forme plus catégorisée et plus symbolique pour décrire le temps sensible. Cette évolution devrait par ailleurs permettre de saisir automatiquement la prévision finalisée du temps sensible et permettre une vérification objective a posteriori.

De telles modifications dans la façon de travailler du prévisionniste ne peuvent être couronnées de succès qu'avec la participation active des divers intéressés. Ce souci constant doit être à la base des préoccupations des personnes chargées de concevoir et de développer les applications pour fournir au prévisionniste un outil de travail à la mesure des difficultés de la tâche qu'il doit accomplir.

THE WESTERN REGION IMAGE ANALYSIS WORKSTATION

by

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ABSTRACT

A number of computer routines have been written to display and manipulate NOAA satellite imagery, received by the Edmonton Satellite Station, on an HP9000. This paper describes these routines, and outlines future plans.

Certains programmes ont été écrits pour afficher et manipuler l'imagerie satellitaire NOAA sur un HP9000. Le text suivant décrit ces programmes, et les points importants des projets futurs dans ce domaine.

IMAGE ANALYSIS HARDWARE AND 3rd PARTY SOFTWARE

The hardware used for image analysis consists of an HP9000 350 SRX with 24 image planes and a 300 Mb disk drive. The operating system is UNIX, and all routines run within the X-Windows environment. The programs were developed with a version of X-Windows which supported only 8 image planes (restricting the available number of colours to 256, drawn from a pallet of 16.7 million). X-windows can now make use of all 24 planes, but the software has not yet been modified to take advantage of this feature. The use of X-Windows does compromise the potential speed of the system, but gives vastly increased flexibility over a non-window system. For example, many different images can be displayed simultaneously, each with their own colour table. Another useful feature is that imagery stored on one computer can be displayed on a different machine, as X-Windows is designed to run over a network.

The application software with which the user interacts consists of two main programs, one used to query the database, and the other to manipulate imagery. The database portion uses XUI (X-Window User Interface), developed by NorthWest Digital Research Inc. However, the display program uses a package called Xrlib from Hewlett Packard (as XUI was not available when these routines were developed). The "look and feel" of these two interfaces are very similar and no inconsistencies are seen by the user. Note that Xrlib is not likely to be supported by HP in the future, hence it is planned to re-write this portion of the display program.

OVERVIEW OF IMAGE ANALYSIS PROGRAMS AND DATA FLOW

This section briefly describes the major programs and data flow which make up the HRPT Image Analysis Station. Due to restriction of space, however, only the database and display routines will be discussed, in any detail, in the following sections.

NOAA satellite imagery is transferred from the Edmonton Satellite Station to the HP9000 and, and stored in a temporary directory. A second routine periodically inspects this directory, and moves any images to the database directory while requesting the database manager to add the imagery to its records. All of these functions occur automatically.

The users' request for satellite imagery are handled by a separate program. This routine maintains a XUI panel through which the user requests imagery which matches some selection criteria. The selection criteria are passed to the database manager which, in turn, sends back a list of matching imagery. This list of available imagery is presented in the XUI panel and when the user selects a particular image, the display program is invoked.

Only one copy of each of the above routines exists at any time except for the display program. A separate copy of this routine exists for every image shown on the computer screen.

DATABASE SELECTION

The user can request imagery which matches any combination of date, time, orbit number and satellite channel (eg, channel 4 for infrared imagery). As mentioned above, a list of matched imagery is returned and displayed in the XUI panel. The user can select the image to display from this list using the mouse. Currently, a rotating database of 100 images is maintained. A separate suite of images is sent to the Alberta and Arctic Weather Centres. This corresponds to approximately 3 days and 1.5 days imagery for the Alberta and Arctic Weather Centres, respectively.

IMAGE ANALYSIS FUNCTIONS

When the display program is invoked, the selected image is shown on the screen, including a small status window in the upper-left-hand corner of the image. Down the right-hand side of the screen appears an Options Panel. It is through this panel that the user interacts with the program. The options are explained below, in varying amounts of detail.

Enlargements - enlargements are performed by selecting this option on the panel, and then "clicking" (using the mouse buttons) two points on the image which represent the diagonal corners of the area to be enlarged. A simple pixel replication scheme is employed.

Reduce - when this option is selected, the image is reduced to a size of 192 x 192 pixels, which serves as an icon. This size was chosen as it is a relatively small box, but large enough so that major cloud features can still be discerned. The full image is returned by clicking a mouse button anywhere in the icon.

Map Control - a background map is provided with each image. Using a switch on the control pattern, the geography can be toggled on and off. Also, it can be moved (but not stretched). This is done quite easily by "clicking" the mouse on a portion of the map, dragging the cursor to where the geography should be registered on the image (ie. visible landmarks are used, such as a small lake), and then releasing the mouse button. The geography is then re-drawn at the new location.

Colour Tables - a number of predefined colour tables are included. These can be selected either by picking from a list, or using the keyboard to type in the name of an existing colour table. By far, most users prefer black and white imagery (ie 256 shades of grey) for synoptic scale work. However, for meso-scale analysis, such as the temperature structure of a Cb cloud-top, a few discreet colours has been found to be most valuable. A utility routine is used to create the colour tables, but this program is not (as yet) available to the general user.

Enhancement Curves - as for colour tables, a number of pre-defined enhancement curves are incorporated into the program and are selected in the same manner as above. It is important to understand the distinction between the colour table (in the way it is used here) and the enhancement curve. The colour table gives the 256 colours that may be used to display the image. The enhancement curve determines exactly how those colours will be applied. Assume, for example, a colour table of 256 grey-shades equally divided from black through white. A linear enhancement curve applied to an early morning visual image (with low light levels) would lead to a very dark image. Instead, an enhancement curve which "boosts" low light levels would be required, so that an input value of (lets say) 50, which would normally be assigned the 50th shade of grey, is instead assigned, for output, grey-shade 200. As seen by the user, the colour table has not changed, as only the original grey-shades are available for display.

Interactive Enhancement - the ability to interactively change the enhancement is, by far, the most used, and useful, option. When this is invoked, a small window pops-up revealing a graph of input data versus output colour. For example, for a linear enhancement the curve is simply a line which extends diagonally from the lower-left to the upper-right hand corner of the window. For the "boosted" visual curve, described above, the graph would merely be a line which extends upwards from the lower-left hand corner at a sharp angle (greater than 45 degrees). This line, representing the enhancement curve, can be dragged into any shape (as long as each input value has only one output value) simply by clicking the mouse over the line, dragging the line to the new position, and then releasing the mouse button. As this is done, the on-screen image changes to reflect changes to the enhancement curve. In this way the user can tailor the curve to his needs. Further, the enhancement curve can be written to a disc file with a user-defined name, and recalled for later use.

Clip Enhancement Curve - this is used in conjunction with the Interactive Enhancement option and colour tables. Normally, the interactive enhancements occur over the entire range of input data. However, using this option, it is possible to restrict all changes, including the application of a colour table, to only some range of input values. A typical use of this routine, for example, is to highlight Cb tops. It is possible to have temperatures warmer than -40 deg C displayed in shades of grey, while having colder temperatures displayed in colour. The procedure is to first apply the grey-shade colour table, then clip the enhancement curve to adjust only temperatures colder than -40 deg C, and finally apply a different colour table. Also note that interactively changing the enhancement curve will now affect only temperatures colder than -40 deg C, the rest of the image will be untouched.

Defaults - the only default action is that of the left mouse button. If the button is depressed anywhere in the image, the data value at that point is displayed in the status window. The units are dependent upon the type of image. For example, for infrared images the value is given in deg C.

FUTURE WORK

A number of additional routines are planned. For most of those listed below, at least prototype software exists. In some cases, it is only a small step before the routine is made operational.

archiving - a routine will be in place by the Spring of 1990 which will be used to archive an image to disk or tape.

remapping of imagery - it is planned to remap the NOAA satellite imagery to polar stereographic projection using the HP9000. This can be done by the Edmonton Satellite Station, but not for every image (due to operational constraints).

contouring - a routine already exists to contour image data. It is planned to contour CMC grid point data, and overlay these charts directly onto the satellite imagery.

multispectral imagery - combining imagery of the same satellite scene taken at different frequencies into a single image to produce "false-colour" images is of great aid in cloud discrimination. Two versions of software have been developed to this end. The version to be initially incorporated into operational use displays the image in 8 image planes only (256 colours), using a pre-set colour table. Because of this, the final image is constructed for the user and no interactive enhancements are possible.

The second version makes use of all 24 image planes. The images used to create the composite are each applied to a separate colour gun, one image per gun (red, green and blue), with 256 shades of each primary colour available. While the 3 images are displayed on the screen simultaneously to give the "false-colour" image, the enhancement curve for each colour gun can be adjusted (in a similar manner as per the afore-mentioned interactive enhancement) giving the user complete control.

3D analysis - software has been written to display CMC grid-point data as a 3D solid body. Simulated flight-paths around the 500 Mb surface, for example, are possible. While interesting, entertaining, and very valuable for particular storm studies, considerable work needs to be done before this application could be moved into operational use on a routine basis.

SUMMARY

The development of the Image Analysis System has been geared heavily toward the operational meteorologist. That is, it performs a number of very basic tasks very quickly. The current system has already proven to be very useful in both the Arctic and Alberta Weather Centres. Future development will be guided by the same principles. It should be noted that the routines described in this paper are relatively generic in that they can be applied to other types of data as well (such as radar data). The attraction of modern computing is that it allows the user to "play" with data in previously unthought-of combinations. This can lead to new and valuable forecasting techniques which is, after all, the ultimate goal of such project development within an operational forecast office.

A PC-BASED PUBLIC FORECAST PREPARATION SYSTEM

by

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ABSTRACT

As part of the Nova Scotia Weather Services Office (WSO) Test Bed, a prototype coded, computerized Public Forecast Preparation System (COPUB) was developed and implemented for operational testing. COPUB was written in TURBO C[1] and operates on a Personal Computer (PC) under DOS. All the forecast composition, from bulletin header generation to completed, transmission ready forecast is performed within the COPUB environment. COPUB allows the forecaster to generate multiple public forecasts within a controlled environment using time-saving abbreviations in place of more lengthy, plain- language words or phrases.

En relation avec le banc d'essai du bureau de services météorologiques de la Nouvelle Ecosse (BSM), un prototype codé, le systeme informatisé pour préparation de prévisions publiques (COPUB) a été développé et testé opérationnellement. COPUB a été écrit en TURBO C et opéré sur un ordinateur personnel (PC) sous DOS. Toute la composition de la prévision, de l'entête jusqu' à la fin de la composition, de même que la transmission du bulletin sont opérés par le programme COPUB. COPUB permet au prévisonniste de générer une multitude de prévisions publiques en utilisant seulement des abréviations prédéterminées au lieu d'un langage formel de mots complets, de pleine expression ou finalement de phrases entières.

BACKGROUND

Within the Atlantic Region, bilingual marine forecasts are composed using a forecaster-prepared, coded bulletin approach (COMAR); the text is dynamically constructed based on the content of the coded bulletin. Because COMAR was a significant success, a project was initiated in the fall of 1988, by AES Atlantic Region, to develop a prototype system for public forecasts. The specifications for the prototype bulletin preparation system (COPUB), consistent with the future introduction of UNIX-based computers into Weather Centres, were completed early in 1989. Software development followed through the summer of 1989.

The prototype was written in TURBO C using a Personal Computer (PC), to allow portability to UNIX, and to take advantage of the use of PCs in the Maritimes Weather Centre (MWC); MWC uses PCs as terminals on the HP-1000 via a terminal emulator, REFLECTION[2]. In the fall of 1989, COPUB was implemented in the Nova Scotia WSO Test Bed for Beta Testing.

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[1]TURBO C is a copyright product of Borland Corporation

[2]REFLECTION is a copyright product of Walker Richer & Quinn, Inc

THE FORECAST PREPARATION ENVIRONMENT

Overview

COPUB is a comprehensive, self-contained bulletin preparation environment. Some of the features of this environment include:

- abbreviations (codes) to phrase/words convertor,
- an internal editor,
- on-line help,
- a bulletin formatter,
- multiple product handling,
- automatic bulletin updating,
- hard copy output,
- direct uploading to HP-1000.

Execution

A forecaster, using a PC as an HP-1000 terminal, executes COPUB using a REFLECTION COMMAND LINE program. When a request for the environment is input, REFLECTION is sent into background, DOS moves to foreground and the preparation environment is activated. The forecaster can then use this environment to prepare one or more bulletins either by updating previous bulletins or beginning with a blank form (Figure 1). When the environment is terminated, the terminal emulator is reactivated and the PC files are uploaded to the HP-1000.

Input and Operation

To eliminate input errors, the functions of COPUB are invoked by selecting from pop-up menus (Figure 2). Items are selected from the menus by moving the highlight bar to the desired selection or, alternately, by pressing a highlighted hotkey. As selections are made, successive pop-ups are displayed until all required inputs are specified. The status of input parameters can be interrogated at any time via a function key. If these settings satisfy the forecaster's requirements, a function key can be used to bypass the menu selection process and invoke immediate execution.

As COPUB cycles from one function to another, it uses pop-ups to prompt for input and to verify specific program activities (Figure 3). For example, prior to commencing a time-consuming operation, a pop-up is displayed to inform the forecaster that COPUB will appear dormant.

Editing and Help

When a form for preparing the forecast is generated, COPUB automatically loads this form into the editor. Likewise once prepared, a text forecast is displayed on the screen within the editor. On-line help is available for assistance with editor commands and to remind the user of abbreviations recognized by COPUB (Figure 4).

Abbreviations

Although the list of recognized abbreviations is extensive (Figure 5), it

is not exhaustive. Convenient procedures exist within COPUB to allow the insertion of non-abbreviated text into the pre-text coding form. With this facility and the ability to actively edit the text product, COPUB does not restrict the forecaster in the wording of the forecast product. Figure 6 shows an abbreviated forecast and the corresponding text.

FUTURE WORK

Using the results of the WSO Test Bed evaluation, further modifications to COPUB will be performed. Development of a UNIX version is planned for use with the next generation of Regional computers.

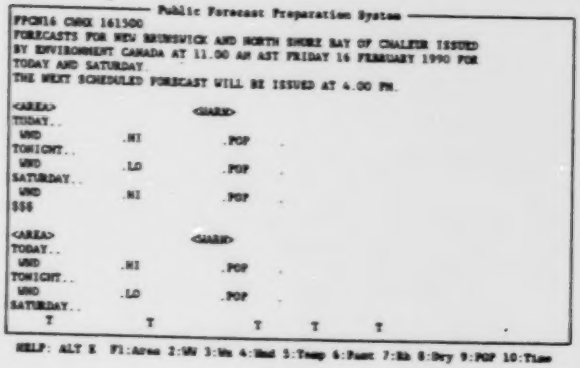

Figure 1: Coding Form Prior to Insertion of Codes

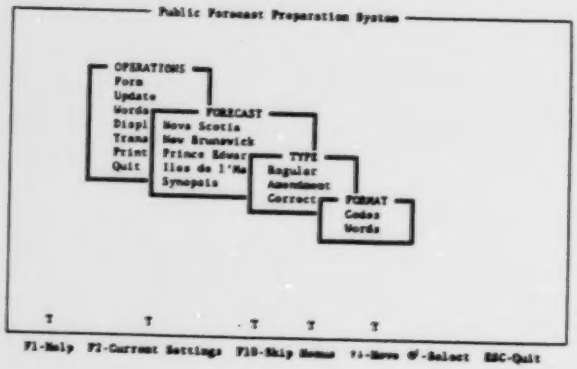

Figure 2: Example of Overlaid Pop-up Input Menus

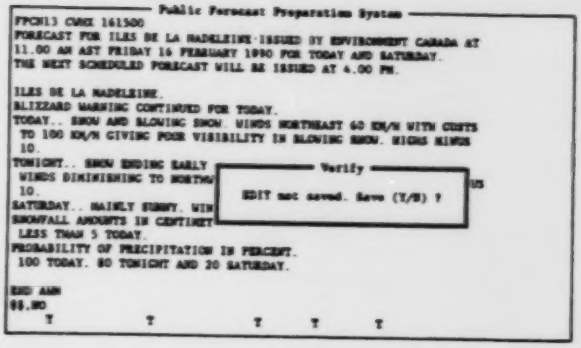

Figure 3: Text Forecast with Input Verification Pop-up

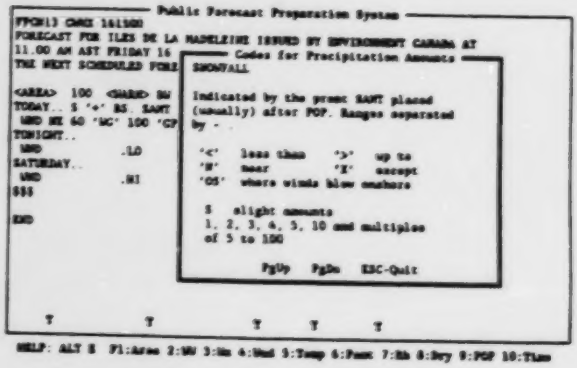

Figure 4: Coded Forecast Under Preparation with Overlaid Help Screen

SKIES

O	overcast
SS	sunny
C	clear
CS	clear skies
CG	clearing
MS	mainly sunny
CGS	clearing skies
CO	clouding over
MC	mostly cloudy
CL	cloudy
S+C	sunny with cloudy periods
SB	sunny breaks
C+S	cloudy with sunny periods
TC	turning cloudy
TS	turning sunny
MC	morning cloudiness
ANC	afternoon cloudiness
EVC	evening cloudiness
ONC	overnight cloudiness
AFC	a few clouds
GC	gradually clearing
VC	variable cloudiness
ICL	increasing cloudiness
CSB	cloudy with sunny breaks

LIQUID PRECIPITATION

R	rain
R+	heavy rain
LR	light rain
OLR	occasional light rain
IR	intermittent rain
PR	periods of rain
RR+	rain at times heavy
OR	occasional rain
RW	showers
ORW	occasional showers
AFRW	a few showers
RWRW+	showers at times heavy
RW+	heavy showers
TRW	thundershowers
TRW+	heavy thundershowers
TTRW+	thundershowers at times heavy
L	drizzle
OL	occasional drizzle
IL	intermittent drizzle
PL	periods of drizzle
LL+	drizzle at times heavy

FREEZING PRECIPITATION

ZR	freezing rain
OZR	occasional freezing rain
IZR	intermittent freezing rain
PZR	periods of freezing rain
ZL	freezing drizzle
OZL	occasional freezing drizzle
IZL	intermittent freezing drizzle
PZL	periods of freezing drizzle
ZP	freezing precipitation
OZP	occasional freezing precip
IZP	intermittent freezing precip
PZP	periods of freezing precip

FROZEN PRECIPITATION

S	snow
S+	heavy snow
LS	light snow
OLS	occasional light snow
IS	intermittent snow
PS	periods of snow
SS+	snow at times heavy
OS	occasional snow
BS	blowing snow
DS	drifting snow
SW	flurries
SW+	heavy flurries
SWSW+	flurries at times heavy
OSW	occasional flurries
AFSW	a few flurries
SWOS	flurries where winds blow onshore

MISCELLANEOUS ELEMENTS

F	fog
FG	foggy
FP	fog patches
C	ice crystals
SP	snow pellets
A	hail
IP	ice pellets
SG	snow grains
HZ	hazy
HC	humid
HH	hazy and humid
P	precipitation
HS	hazy sunshine

TEMPERATURE TRENDS

'BK'	bitterly cold
'CBK'	continuing bitterly cold
'CK'	continuing cold
'VK'	very cold
'CVK'	continuing very cold
'MK'	much colder
'CC'	continuing cool
'VC'	very cool
'CVC'	continuing very cool
'MC'	much cooler
'CM'	continuing mild
'VM'	very mild
'CVM'	continuing very mild
'MM'	much milder
'CW'	continuing warm
'VW'	very warm
'CVW'	continuing very warm
'MW'	much warmer
'CHT'	continu'ng hot
'VH'	very hot
'CVH'	continuing very hot
'MH'	much hotter

MODIFIERS

'AC'	along the coast
'NC'	near the coast
'AAC'	along the Atlantic coast
'NAC'	near the Atlantic coast
'AFC'	along the Fundy coast
'NFC'	near the Fundy coast
'CG'	changing to
'I'	intensifying to
'D'	diminishing to
'BC'	becoming
'T'	tapering to
'M'	mixed with
'+'	and
'O'	or
'ATM'	at times mixed with
'CH'	chance of
'DV'	developing
'E'	ending
'P'	persisting
'C'	continuing
'B'	beginning
'F'	followed by
'SCT'	scattered
'ISOL'	isolated
'OCNL'	occasional
'LCL'	locally
'EXT'	extensive
'OS'	where winds blow onshore
'IL'	inland
'CST'	coastal
'X'	except
'LI'	lifting

Figure 5: A List of Weather Codes Recognized by COPUB

```
------------------- Public Forecast Preparation System -------------------
<AREA> 31                     <WARN> SW 'IF' [NGT]
TODAY.. LS. SAMT '<' 5.
 WND 20          .HI M2 - P1    .POP 90 .
TONIGHT.. SS+. SAMT '>' 15.
 WND NE 40       .LO M8          .POP 100.
SATURDAY..CG [M] [THEN] MS.
 WND NW40 'WC' 70 'GBS'. HI M5    .POP 20 .
$$$

<AREA> 32                     <WARN>
TODAY.. AFC [TN]. CO [TA].
 WND 20          .HI  M5         .POP 20 .
TONIGHT.. S 'B' [LTE]. SAMT 2-5.
 WND NE 30       .LO M10         .POP 100.
SATURDAY.. S 'E' [M] 'F' CG.
 WND 'I' NW 40    .HI M7         .POP 70 .
$$$

END
    T          T           T     T      T
HELP: ALT E  F1:Area 2:WW 3:Wx 4:Wnd 5:Temp 6:Pamt 7:Rh 8:Dry 9:POP 10:Time
```

```
------------------- Public Forecast Preparation System -------------------
MAINLAND NOVA SCOTIA.
HEAVY SNOWFALL WARNING ISSUED FOR TONIGHT.
TODAY.. LIGHT SNOW. WINDS 20 KM/H. HIGHS MINUS 2 TO PLUS ONE.
TONIGHT.. SNOW AT TIMES HEAVY. WINDS NORTHEAST 40 KM/H. LOWS MINUS
 8.
SATURDAY.. CLEARING IN THE MORNING THEN MAINLY SUNNY. WINDS
 NORTHWEST 40 KM/H WITH GUSTS TO 70 KM/H GIVING BLOWING SNOW.
 HIGHS MINUS 5.
SNOWFALL AMOUNTS IN CENTIMETRES.
 LESS THAN 5 TODAY. UP TO 15 TONIGHT.
PROBABILITY OF PRECIPITATION IN PERCENT.
 90 TODAY. 100 TONIGHT AND 20 SATURDAY.

CAPE BRETON.
TODAY.. A FEW CLOUDS THIS MORNING. CLOUDING OVER THIS AFTERNOON.
 WINDS 20 KM/H. HIGHS MINUS 5.
TONIGHT.. SNOW BEGINNING LATE THIS EVENING. WINDS NORTHEAST 30
 KM/H. LOWS MINUS 10.
SATURDAY.. SNOW ENDING IN THE MORNING FOLLOWED BY CLEARING. WINDS
 INCREASING TO NORTHWEST 40 KM/H. HIGHS MINUS 7.
SNOWFALL AMOUNTS IN CENTIMETRES.
    T          T           T     T      T
HELP: ALT E  F1:Area 2:WW 3:Wx 4:Wnd 5:Temp 6:Pamt 7:Rh 8:Dry 9:POP 10:Time
```

Figure 6: An Abbreviated Forecast (left) and the Corresponding Text (right)

AMELIORATIONS AUX SERVICES METEOROLOGIQUES POUR L'ARMEE DE TERRE

par

G. Kierstead et C. Doyle du Service météorologique des Forces canadiennes, M. Lanoue du Pacific Weather Centre et Adjum Y. Plante des Forces canadiennes.

R E S U M E

Les récentes améliorations aux services météorologiques à l'armée de terre canadienne sont tracées. Ces améliorations ont eu lieu dans trois domaines distincts. Le premier est l'emploie d'Officiers météorologiques des Forces de réserve lors des principaux déploiements de l'Armée de terre. Ceci a permis à quelques météorologues de se familiariser avec les besoins en services météorologiques de cet usager spécial. Un réseau de 8 stations météorologiques automatiques fut installé récemment sur le champs de tir de Gagetown. Le rôle principal de ce meso-réseau est de fournir les données nécessaires au calcul d'indices de feu de forêt mais le réseau pourrait servir davantage. Troisièmement, afin d'améliorer l'appui météorologique pour l'artillerie, un logiciel a été développé pour réduire les données et produire les messages aérologiques et, des micro-ordinateurs robustes ont été mise en service.

DEVELOPMENTS IN ARMY METEOROLOGICAL SERVICES

by

G. Kierstead and C. Doyle of the Canadian Forces Weather Service, M. Lanoue of Pacific Weather Centre, and MWO Y. Plante of the Canadian Forces.

A B S T R A C T

Recent enhancements in meteorological support services to Canada's Land Forces are described. These developments occurred in three seperate areas. The first is the use of Reserve Force Meteorological Officers on large scale Army field exercises. This has enabled meteorologists to become more acquainted with this special user's particular meteorological service support needs. Recently, 8 Campbell Scientific automatic weather reporting stations were installed over the Gagetown Range. The mesonet's primary role is to monitor fire weather indices but they offer potential for much more. Thirdly, to improve artillery meteorological support capabilities, a software package to perform aerological data reduction and message generation was developed and rugged microcomputers were introduced into service.

A R M Y M E T E O R O L O G I C A L S U P P O R T

Introduction

The Land Forces have employed the services of Meteorological Officers on recent large scale exercises. This has enabled a limited number of meteorologists to become familiar with this particular user's specific meteorological service support needs. Given the potential for much greater use of part-time Reserve personnel in Canada's armed forces, the mechanics of how this is accomplished are briefly reviewed.

Background

The Rendez-Vous series of divisional exercises held in each odd year since 1981 first employed the services of a Meteorological Officer in 1985. For RV-87 an AES meteorologist from CFB Trenton participated as Officer Commanding a Combat Meteorological Company which grouped all meteorological resources intc one ad hoc unit. Four Meteorological Officers participated in RV-89. This enabled weather forecasts to be produced in situ for the first time on an Army exercise.

Army Meteorological Requirements

Products provided to a field army on deployment include the full range of public and aviation products. Aviation products are tailored specifically to low level and helicopter requirements. In addition to the public-type forecast called a METREP all army units receive nuclear and chemical downwind messages in North Atlantic Treaty Organization (NATO) formats. The Divisional Headquarters also requires forest fire indices, detailed astronomical data, trafficability data, and comfort and concealment data. A meteorological impacts assessment grid is prepared and presented at Divisional Headquarters along with every briefing. This is a new and important product which summarizes all other meteorological data in terms that army commanders are able to assimilate. It is really a rudimentary Tactical Decision Aid (TDA) which would lend itself well to computer production.

Terms of Service

The Canadian Forces recognizes the AES MOC course and prior Bachelor's degree as the essential prerequisites for direct entry as an officer in the classification of meteorology. Enrollment and commissioning in the Reserve Force is thus greatly simplified. Full time service for the short periods of exercises is always on a completely voluntary basis. Positions offering part-time employment a few evenings a week with occassional weekend work will likely soon be created in Toronto and Montréal with other major urban centres to follow with fewer positions some time later.

G A G E T O W N M E S O N E T

Introduction

The Department of National Defence has installed a dense mesonetwork of automatic weather stations on the Canadian Forces Base (CFB) Gagetown Training Area located in southern New Brunswick. The network is a telemetry based collection of eight automatic weather stations, seven of them permanently sited and one portable.

The forest fire problem is more acute on military ranges because incendiary devices are often used in training activities. Fire weather assessment must be as precise as possible to avoid unnecessarily restricting intensive training programmes or conversely, permitting unrestricted training activities during periods of high fire danger. The purpose of the network is to improve the quality of fire weather data used by the Base but the system will run on a 24/7 basis throughout the year.

Equipment Description

Each weather station consists of a standard AES anemometer tower with a number of appendages for power, communications, sensors, and controls. The hub of each station is a Campbell Scientific Canada Corp data logger, model CR10. Attached to it are sensors for temperature, humidity, wind speed and direction, and rainfall rate and amount. The datalogger is very flexible and any variety of sensors can be added as needed. An on-board radio transmits data to a base station. Each station is powered by batteries which are recharged by solar cells. The base station consists of an RF modem, radio, and an IBM PS/2 model 80.

Data, Availability, and Futur Additions

The data loggers presently collect hourly weather for each station, daily statistics compatible with the AES climate network, and fire weather index input parameters. Archive data is retrieved daily at 1301 local and real-time data as required. It is intended to make the data base available to all interested parties. It is also intended to make the network itself available to anyone wishing specialized data collection programmes. The archive will be structured for compatibility with the AES national climate archive which should permit consistency in handling of the data base when incorporated into larger scientific studies.

The network was procured based on the need for improved fire weather data on the CFB Gagetown Training Area. However, work is proceeding on procuring photometers and radiometers for one or more stations and it is intended to outfit some stations with barometers. Soil moisture and snow depth are two other parameters of particular interest.

A E R O L O G S O F T W A R E

Introduction

The AEROLOG software was developed to meet the needs of an aerological section producing meteorological messages for military and civilian agencies. It was developed by the CFB Gagetown Meteorological Troop using ADRES algorithms to derive the meteorological data. Other routines, developed in conjunction with the University of New Brunswick, reduce the data numerically rather than via the old graphical method using Adiabatic Diagrams.

Outputs

All artillery meteorological messages are coded in accordance with NATO standards. Standard ballistic (Surface-to-Air and Surface-to-Surface) and computer meteorological messages are available in addition to the Standard Fallout Meteorological Message. AEROLOG also codes all upper air data using WMO standards and produces.

Requirements

AEROLOG is written in Turbo PASCAL and is available in compiled form as an executable file. It requires MS DOS 2.1 or later and 256 K of memory. Any IBM compatible micro computer in conjunction with any type of video display will generate output onto virtually any DOS text printer.

Software description

AEROLOG is a semi-automatic data processing package and so requires that raw data be manually transferred from the recorders to the computer via the keyboard. The following entries are necessary for each data level: time, contact value, temperature and humidity ordinate values. Elevation and azimuth angles are also required to calculate wind vectors. Computation is performed as data is entered thus enabling output messages to be available about four minutes after balloon burst. Comprehensive data summaries are printed out and all flight data is archived to disk.

Army Aerological Teams

Canada's Land Forces have recently acquired a number of GRID SE-T (Severe Environment - TEMPEST) micro-computers to run AEROLOG on field deployments with artillery regiments. This, in conjunction with new 2.5 ton trucks and shelters, and trailer-mounted GMD antennas, has significantly enhanced our deployment capability. These experienced, rugged, deployable aerological teams have been used in the past for special studies. They could also be extremely valuable to assist in monitoring environmental disasters.

APPROCHES ALTERNATIVES DE PREVISION DU TEMPS A L'AIDE DES MODELES NUMERIQUES

Richard Verret (Centre météorologique canadien)
Alain Patoine (Formation professionnelle)

RESUME

On montre que le niveau de détail dans le champ de tourbillon dépend fortement de la résolution utilisée. Par ailleurs, en se référant à la théorie du mouvement vertical, on conclut que pour la prévision de phénomènes à des échelles sub-synoptiques, il nous faut réviser notre approche et recourir à des outils alternatifs. Parmi les différentes possibilités, le mouvement vertical du modèle EFR a été examiné de près. Nous avons trouvé qu'il s'agissait là d'un outil valable.

ABSTRACT

It is shown that the level of detail in the vorticity field is strongly dependent on resolution. On the other hand, referring to vertical motion theory, we conclude that, to forecast sub-synoptic scale phenomena, we have to revise our approach and use alternative tools. Among different possibilities, the vertical motion field of the RFE numerical model was looked at closely and we found that it is a valuable tool.

INTRODUCTION

Suite à l'implémentation récente de schémas d'analyse et de modèles numériques à plus haute résolution, des questions ont été soulevées quant à la philosophie à adopter face au tourbillon devenu extrêmement détaillé.

Evidemment, ce phénomène a un impact majeur sur la façon de travailler du prévisionniste. En effet, celui-ci a l'habitude de recourir à des creux et crêtes d'ondes courtes pour positionner ses bordures nuageuses. Aujourd'hui, le niveau de détail existant dans le champ de tourbillon l'empêche souvent de procéder de la sorte.

En examinant ce problème de près, nous avons déterminé que l'augmentation du niveau de détail dans le champ de tourbillon, qui coïncide avec une augmentation de la résolution, est un phénomène parfaitement normal.

Par ailleurs, les principes théoriques sur lesquels est basée l'utilisation du tourbillon de la façon décrite plus haut, doivent être remis en question lorsqu'on travaille à haute résolution (échelles sub-synoptiques). En effet, à ces échelles, de nombreux termes de contrainte du mouvement vertical, négligeables à l'échelle synoptique, deviennent significatifs. Il est évident qu'il serait trop demandé aux météorologiste de considérer tous ces termes de contrainte. Il nous faut donc réviser notre approche et recourir à des outils alternatifs de prévision.

Parmi les différentes possibilités, le mouvement vertical du modèle a été examiné de près puisque le modèle a la possibilité de considérer tous les effets dynamiques et physiques importants

à sa propre résolution. Nous avons trouvé qu'il s'agissait là d'un outil valable de prévision.

Les résultats présentés ici sont très fragmentaires et le lecteur intéressé pourra consulter Verret et Patoine (1990) dans lequel tous les détails sont précisés.

EFFET DE LA RESOLUTION SUR LE CALCUL DU TOURBILLON GEOSTROPHIQUE

La figure 1a représente un champ de hauteur (traits pleins ouverts) défini de façon analytique et le champ de tourbillon géostrophique (traits fermés pleins (valeurs positives) et discontinus (valeurs négatives)) qui en découle.

La seule différence entre les deux images est que le calcul du tourbillon est effectué sur une grille de 100 par 100 à gauche et de 25 par 25 à droite. C'est donc la résolution qui change d'une image à l'autre.

On constate que le tourbillon géostrophique associé à cette "onde longue" (par rapport aux longueurs de maille utilisées) est similaire dans les deux cas.

Par la suite, on aditionne à ce champ une "onde courte" (10 fois plus courte que l'"onde longue") dont l'amplitude est 100 fois plus petite. Cette perturbation est située juste à droite du creux d'"onde longue".

On calcule à nouveau le tourbillon géostrophique sur les deux grilles et on obtient la figure 1b. On constate que le tourbillon associé à cette "onde courte" dépend fortement de la résolution de la grille d'analyse et qu'à haute résolution, on obtient une valeur de tourbillon plus de deux fois supérieure à la valeur du maximum associé au creux d'"onde longue".

De cet exercice, on conclut qu'il est normal qu'en augmentant la résolution on voit apparaître de multiples extremums dans le champ de tourbillon puisqu'on permet maintenant à de plus courtes longueurs d'ondes d'exister.

Evidemment, dans le cas du modèle, le tourbillon auquel on s'intéresse est le tourbillon du vent; cependant, il est permis de croire que la même démonstration pourrait être faite avec le champ de vent.

EFFET DE LA RESOLUTION SUR LE TOURBILLON DANS LE MODELE EFR

Afin d'étudier plus à fond l'effet de la résolution sur le tourbillon nous avons conduit quelques expériences à l'aide du modèle EFR. Nous avons intégré le modèle opérationnel à 100 km de résolution (dans la fenêtre centrale) et une version modifiée ayant 400 km de résolution.

La figure 2a montre les cartes de 500 hPa hauteur/tourbillon obtenues pour un cas donné. On voit que le tourbillon est beaucoup plus détaillé à haute résolution.

La figure 2b montre les champs d'advection de tourbillon. Etant donné le détail accru dans le tourbillon, on constate que l'advection de tourbillon change de signe sur de courtes distances à 100 km de résolution contrairement à ce qui se passe à 400 km de résolution. De façon générale, les extremums ne sont pas situés aux mêmes endroits et les grandes zones (positif ou négatif) ne sont pas nécessairement préservées.

Nous avons aussi tracé le mouvement vertical à 700 hPa (figure 2c). Contrairement à ce qui se passe pour l'advection de tourbillon, les grandes zones (positif ou négatif) sont, en général, préservées et les extremums se retrouvent, à peu près, aux mêmes endroits. En fait, le plus grand changement se trouve au niveau de l'intensité des extremums.

Nous concluons qu'une augmentation de la résolution du modèle produit une augmentation du niveau de détail dans le champ de tourbillon et que le mouvement vertical est beaucoup moins perturbé par un tel changement.

THEORIE DU MOUVEMENT VERTICAL

Le météorologiste opérationnel est intéressé par l'advection de tourbillon parce qu'il s'agit d'un des termes de contrainte du mouvement vertical. A ce stade-ci nous posons les questions suivantes: Est-ce que l'advection de tourbillon est un terme de contrainte dominant et dans quels cas? Quels sont les autres termes de contrainte?

L'équation oméga qui est obtenue à partir de la théorie quasi-géostrophique comprend 2 termes de contrainte du mouvement vertical; l'un est lié à l'advection de tourbillon et l'autre à l'advection de température.

La théorie quasi-géostrophique est basée sur la supposition qu'on travaille à l'échelle synoptique. Donc, si on veut travailler à plus haute résolution que celle correspondant à cette échelle, il faudra éventuellement considérer les termes laissés de côté par cette théorie.

Krishnamurti (1968a) développa une équation diagnostique pour oméga comportant 12 termes de contrainte. Il évalua (Krishnamurti (1968b)) la contribution au mouvement vertical de ces 12 termes de contrainte pour un cas de développement. Le calcul des différences finies fut effectué sur une grille de 200 km de résolution. Il démontra qu'à cette échelle les termes dominants sont encore ceux reliés à l'advection de tourbillon et de température. Cependant, plusieurs autres termes peuvent contribuer de façon non-négligeable au mouvement vertical par moment et par endroit.

On conclut donc qu'à haute résolution, on ne peut plus se permettre de ne considérer que l'advection de tourbillon et de température pour estimer le mouvement vertical.

MOUVEMENT VERTICAL DANS LES MODELES NUMERIQUES

Dans les modèles numériques, le mouvement vertical est calculé en intégrant la divergence selon la verticale.

Etant donné que les modèles de prévisions opérationnels modernes sont basés sur les équations primitives, il est clair que tous les termes dynamiques produisant de la divergence sont incorporés dans le calcul du mouvement vertical. De plus, ces modèles considèrent tous les effets physiques importants (e.g. libération de chaleur latente).

Donc, dans des situations pour lesquelles on a confiance en la prévision des différents champs du modèle, on devrait aussi considérer le mouvement vertical calculé.

EVALUATION OBJECTIVE DU MOUVEMENT VERTICAL DU MODELE EFR

Tous les champs extraits du modèle EFR ont été interpollés à 264 stations canadiennes, afin de calculer les corrélations avec les observations de quantités de précipitations sur six heures.

Les quantités de précipitations sur six heures, le taux instantané de précipitations, le mouvement vertical et l'humidité relative prévus par le modèle EFR, sont les champs qui montrent les meilleures corrélations avec les observations de quantités de précipitations sur six heures.

Le mouvement vertical prévu par le modèle EFR, apparaît donc comme un bon outil prévisionnel.

Par ailleurs, les corrélations entre les observations de quantités de précipitations sur six heures et l'advection du tourbillon est très faible. De même, aucune relation entre la prévision du laplacien de l'advection des températures et les observations des quantités de précipitations n'a pu être décelée.

L'advection du tourbillon n'apparaît donc pas comme un bon outil pour prévoir les quantités de précipitations.

EVALUATION SUBJECTIVE DU MOUVEMENT VERTICAL DU MODELE EFR

Le champ de mouvement vertical à 00 heure n'a pas été, jusqu'à maintenant, disponible pour les prévisionnistes; c'est donc un champ méconnu. On est en droit de se demander quelle est la validité de ce champ. C'est une des choses que nous avons évalué subjectivement.

La prévision de 00 heure du mouvement vertical montre des patrons météorologiquement acceptables et est tout aussi réaliste qu'aux autres temps de prévision (formes de virgules et autres); son intensité est du même ordre qu'aux autres temps de prévision.

Nous avons aussi évalué, de façon subjective, la correspondance qu'il y a entre le patron de mouvement vertical au temps initial et le patron de précipitations observées dans les 12 heures précédentes.

De façon subjective, nous avons constaté une bonne correspondance entre mouvement vertical ascendant significatif (quelques microbars/sec et plus) et la présence de précipitations.

Finalement, nous avons évalué la consistance temporelle du mouvement vertical en comparant les différentes prévisions de ce champ valides au même temps mais produite avec différents temps de prévision.

Nous avons trouvé que la consistance temporelle était, de façon générale, excellente.

PLAN DU LABORATOIRE

Le but du laboratoire est de faire connaître différents outils utiles au prévisionniste dans l'accomplissement de sa tâche. De plus, nous voulons susciter chez le participant une réflexion quant à la façon de produire les prévisions et aux outils qui sont utilisés.

Présentation (45 min.): On couvrira rapidement, et sans plus de détail, ce qui a été expliqué dans ces quelques pages.

Etude de cas (75 min.): On demandera au participant de produire une prévision à l'aide d'outils "traditionnels". Par la

suite, on lui fournira d'autres outils "alternatifs" et on lui demandera de comparer les deux façons de travailler.

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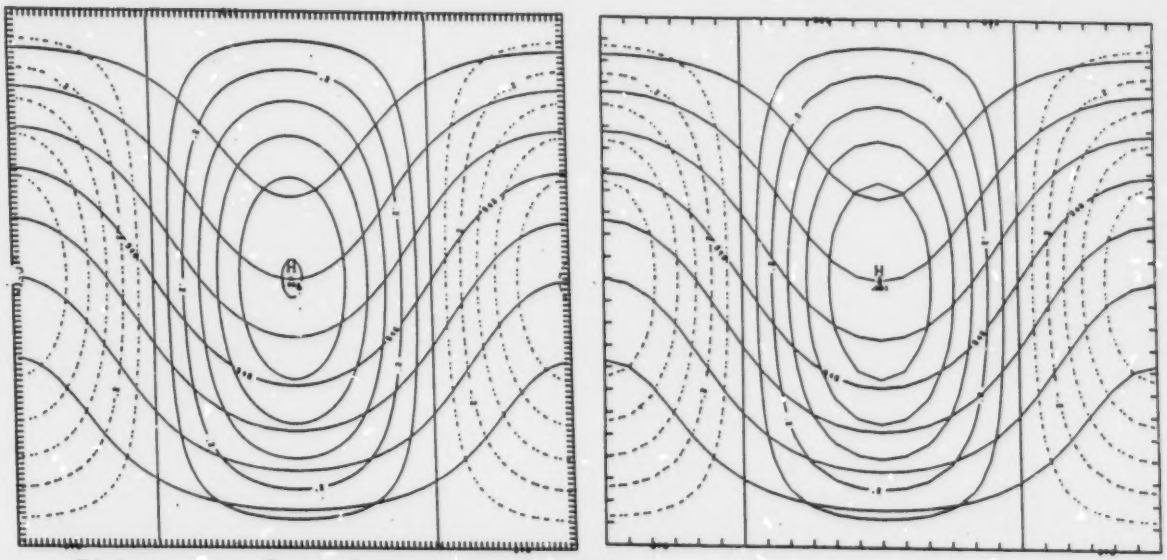

Figure 1a: Onde longue seulement
(100 X 100) à gauche et (25 X 25) à droite

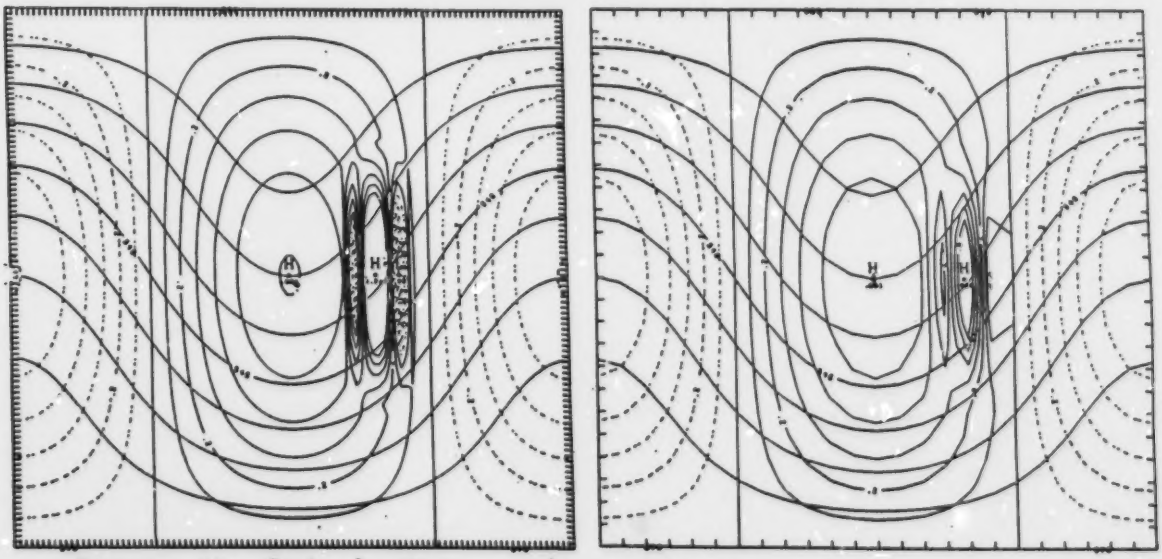

Figure 1b: Onde longue + onde courte
(100 X 100) à gauche et (25 X 25) à droite

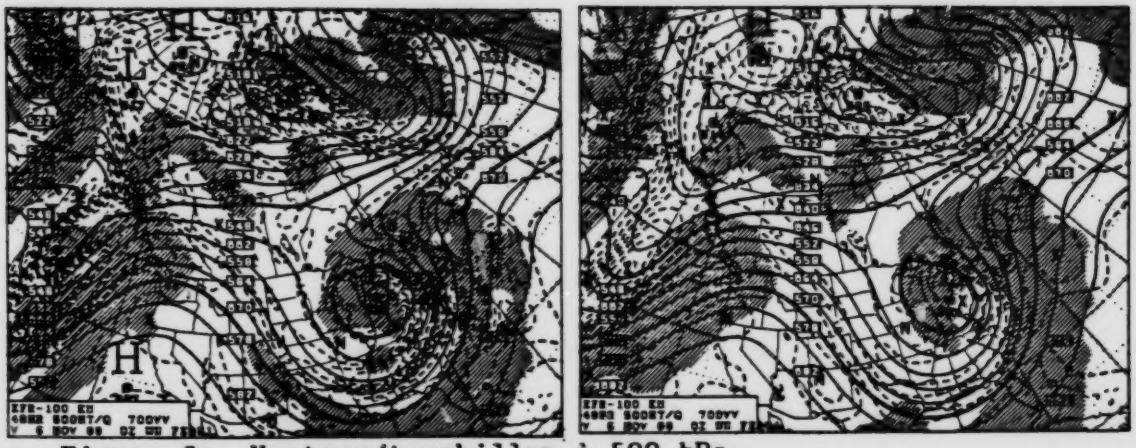

Figure 2a: Hauteur/tourbillon à 500 hPa.
Résolution de 100 km à gauche et 400 km à droite.

Figure 2b: Advection de tourbillon à 500 hPa (ombré positif).
Résolution de 100 km à gauche et 400 km à droite.

Figure 2c: Mouvement vertical à 700 hPa (ombré ascendant).
Analyse faite à tous les microbar/sec.
Résolution de 100 km à gauche et 400 km à droite.

ALTERNATIVE APPROACHES TO FRONTAL ANALYSIS

LABORATORY SESSION

By

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ABSTRACT

Frontal analysis in Canada is generally conducted following the Polar Frontal model developed in the 1940's and 50's. When attempting to incorporate radar and satellite information, the analyst frequently finds shortcomings in the application of a standard 3 (or 4) front model, as well as in the typical airmass nomenclature. This laboratory session will explore alternative analysis options for a typical case in light of more current thinking in frontal modelling. Analysis activities will attempt to identify options for a more accurate 3-dimensional representation of atmospheric structures than is allowed by standard practice.

RÉSUMÉ

Généralement, au Canada, l'analyse frontale se fait en suivant le modèle frontal polaire développé dans les années 40 et 50. Lorsque l'analyste tente d'utiliser les données radar et satellitaires, il se butte souvent à des faiblesses dans l'application d'un modèle frontal standard (3 ou 4 fronts) aussi bien que dans la nomenclature typique des masses d'air. Ce laboratoire examinera d'autres options d'analyse pour un cas typique en se servant d'idées nouvelles dans la modélisation frontale. On essaiera d'identifier des choix pour une représentation plus exacte des structures atmosphériques que les pratiques standard nous le permettent.

INTRODUCTION

Frontal analysis is possibly one of the more complex analysis tasks performed by the operational meteorologist. It encompasses the consideration and synthesis of many sources of data to conform to a coherent picture of a three dimensional structure in the atmosphere. Even with recent advances in numerical weather prediction and the availability of alternative model output, it is still the basic frontal analysis that occupies an important part of the meteorologist's time.

In the past decade, the concept of a front has evolved significantly with advances in data analysis and the use of satellite and radar imagery. It is therefore prudent to apply these models operationally in order to diagnose as completely as possible the atmospheric processes at work.

OBJECTIVES

The lab is designed to investigate frontal analysis from an operational perspective in light of recent thinking in frontal conceptual models. This "back to basics" approach should result in more questions than answers. In particular, points of discussion could centre around the following:

1. Should meteorologists be compelled to analyse fronts so that they are physically consistent with an implied conceptual model, or should frontal analysis be a utilitarian tool only?

2. Is the current suite of frontal symbology adequate to describe the set of possible frontal structures (or non-frontal structures) ?

3. Why is there such a large inconsistency in the operational application of frontal conceptual models?

4. How can numerical weather prediction output be used optimally to help diagnose and forecast fronts?

ACTIVITIES

By way of an introduction, the participants will be given a brief overview of operational frontal analysis and some of the conceptual models that are currently in use.

Participants will then work in groups to carry out a series of frontal analyses on a case study. Each group will be supplied with products that are available operationally. The particular case of a frontal system crossing southern Ontario, was chosen because it represented a typical problem in frontal analysis, one that is encountered frequently.

The results of the analyses will be discussed among the groups, with justifications given for frontal placement. These will be viewed in light of internal and temporal consistency as well as operational usefulness. The relationship of the frontal diagnosis to NWP output will also be explored.

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MARINE COASTAL WIND DIAGNOSIS AND FORECASTING

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OBJECTIVES:

1. The participants will use accepted techniques to diagnose open water marine winds. (25 minutes)

Activity: Participants will be given a brief review of the main forcing terms which result in the marine, open-water wind field (eg. isobaric, isallobaric, curvature, stability, etc.) and their limitations in an operational setting. Given a typical winter weather situation taken from CASP the participants will diagnose (both quantitatively and qualitatively) the open water wind. From this the relative merit of each of the forcing terms and their sensitivity will be illustrated. In addition, recommendations will be proposed on how to operationally apply the terms.

2. The participants will apply the wind diagnosis skills to prepare an open water wind forecast. (25 minutes)

Activity: Participants will be supplied with prognostic, isobaric, and isallobaric charts for the same case, along with any necessary supplementary forecast data (eg. air temperature fields, dew point temperature fields, sea-surface temperature fields, etc.) and will prepare an open water wind forecast using accepted techniques. Solutions will be verified with data from CASP. A brief discussion on the validity of accepted techniques and possible areas to focus on for future improvements will be initiated.

3. The participants will diagnose marine coastal winds by investigating the coastal contamination of open water winds. (70 minutes)

Activity: Participants will be given a review of various coastal wind effects and the physical reasons for them. Through an interactive process and the use of several cases the participants will diagnose the winds (both quantitatively and qualitatively) at several coastal locations. The importance of the diagnosis of coastal winds upon the forecast process of open water winds will be discussed. Comments on methods of quantifying different coastal effects will be solicited.

Doppler Radar Laboratory

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Abstract

Doppler radars will be part of operational forecast offices in the future. This laboratory will provide an opportunity for participants to get some hands on experience with this technology. Instructors with Doppler experience will guide the participant through several case studies from all seasons. Available cases for interpretation are: (i) basic wind fields, (ii) frontal situations, (iii) mesoscale precipitation systems, (iv) mesocyclone/tornadic thunderstorms, (v) severe gust front wind storm and (vi) downbursts.

Résumé

Les radars Doppler feront éventuellement partie intégrante des bureaus de prévisions opérationnels. Le présent laboratoire donnera l'occasion aux participants de se familiariser avec ce nouvel outil. Le instructeurs aideront les participants dans l'interprétation d'une panoplie d'études de cas correspondants à différentes situations météorologies. En voici la liste: i) champs de vitesse de base, ii) situations frontales, iii) systèmes de précipitations à la méso-échelle, iv) tornadoes/mésocyclones, v) fronts de rafales violents et, vi) rafales descendantes.

1. Introduction

Weather radars using the Doppler principle can measure the velocity of hydrometeors moving toward or away from the radar. They have been used in weather research for many years. Successful use of Doppler radar in a pseudo operational environment was demonstrated in the late 1970's in the Joint Doppler Operational Project using the National Severe Storm Laboratories radars in Oklahoma. Highly trained meteorologists were used in the study and the results showed that 50-60% probability of detection for F2 (or greater) tornadoes could be expected. There was still some question as to the results that could be expected using meteorologists with less training.

Doppler radars have been installed for operational use since the mid-eighties at King City, Ontario, Montgomery, Alabama, Marseilles, Illinois and in Sweden (development environment). The most sophisticated of these systems is the one located at King City, Ontario which has computer control, volume scanning, velocity unfolding, lightning information, real-time data processing and archiving capa-

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bility.

Doppler radar will be a part of the future forecast office. The Atmospheric Environment Service of Canada has agreed in principle that Doppler radars will be radars of the future. The Next Generation Radar (NEXRAD) project in the United States is currently at the begining of the implementation phase of 113-175 radars. The Terminal Doppler Weather Radar (TDWR) project is near delivery of its first radar for aviation protection. There are plans for the installation of Doppler radars in Europe for hydrological applications.

2. The Laboratory

This laboratory will introduce the participant to Doppler radar imagery and technology. Emphasis will be on the interpretation of radial velocity maps, though reflectivity maps (corrected for ground clutter) and spectral width maps will be used as well. Weather offices in the future will be equipped with interactive workstations for control, processing and display of radar images. The laboratory will consist of interactive systems which will allow the user to display several radar images simultaneously. Instructors will be available at each workstation to guide the participants through several cases ranging from interpretation of mean wind fields to the identification of mesocyclones and downbursts.

The King Automated Radar Display System (KARDS) which is used operationally at the Ontario Weather Centre will also be available. It is a interactive display system which can display up to four images simultaneously that can instantly recall and display any of the other display products. Animation, zoom, pan and scroll can be applied to any time sequence. Mesocyclone tracking using an artificial intelligence approach is a new feature.

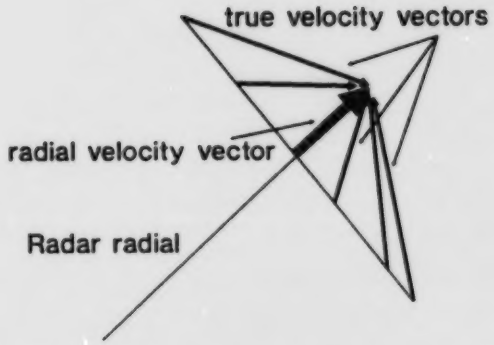

Figure 1: The fundamental ambiguity of Doppler radar is that there is a family of true velocity vectors which produce the same radial velocity vector.

3. Interpretation Techniques

The fundamental problem of Doppler radar is the inherent ambiguity which arises from an incomplete measure of the wind field. Only the component of the wind vector *radial* to the the radar can be measured by the radar. The perpendicular or transverse component is unknown. There is an infinite family of true wind vectors which can have a given radial velocity vector since the transverse component can be arbitrarily chosen. This is illustrated in Fig.1 which shows a family of true velocity vectors which produce the same radial velocity vector. This dilemma can only be resolved using some assumptions based on reasonable conceptual models of air flow in the atmosphere.

3.1 Uniform Wind Fields

Fig. 2 is a schematic of a wind field on a plan position indicator (PPI) surface. This is a horizontal mapping of the three dimensional conical surface pre-

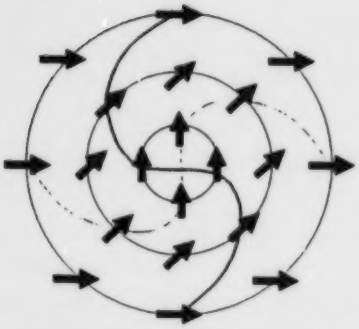

Figure 2: Schematic of true wind vectors on a PPI surface.

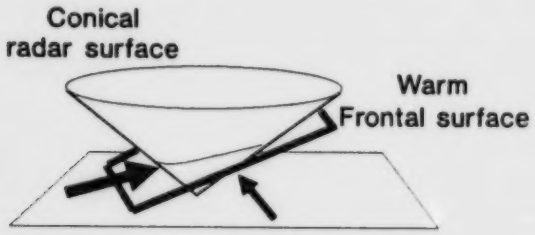

Figure 3: Warm front producing wind pattern of Fig. 2

scribed by rotating the radar through 360° in azimuth while pointing at a fixed angle above the horizon. On this surface, height above the ground is a direct function of range. The concentric rings indicate lines of constant range from the radar located at the centre. The arrows representing the true wind vector on the innermost/outermost ring is close to /far from the ground. In this figure, the wind at a given height is constant in speed and direction but the speed and direction is changing with height/range. Fig. 3 shows the meteorological situation that could produce this flow pattern.

The S shaped thick solid line is drawn through positions of *zero* radial velocity or where the wind vector is *perpendicular* to the radial direction from the radar. The dashed line is drawn through positions of extrema of radial velocity or where the wind vector is *parallel* to the radar radial. If the wind is uniform at a given height, as in this case, then the dashed line is 90° out of phase with the solid line. This relationship is used for the interpretation of uniform wind fields. For a given range, the azimuth of zero radial velocity will be 90° from the wind direction at that height. The value of the extrema which should be located 90° away gives the wind speed. Any deviation from this pattern is interpreted as deviation from the uniformity assumption. Even if all of the prescribed conditions are satisfied, the wind field may not be uniform since there are other solutions to this pattern; however, in practice this is not usually the case.

In practice, the PPI may not be completely filled with targets and only partial images are presented. This complicates the interpretation because it is not always possible to locate the zero line or the extrema value. Note that if there are sufficient targets near the upwind or downwind positions, this may be sufficient to estimate the wind vector. This requires that there are sufficient targets to define the extrema which is not the case with the mesoscale jets associated with many precipitation systems. The proper interpretation of these latter systems require conceptual models of the airflow through these systems which are only now beginning to evolve.

3.2 Mesocyclone/Tornadoes

The identification of mesocyclones, the precursors of tornadoes, requires the recognition of patterns on spatial scales of the order of 5 to 10 kilometers, 5 to 10 pixels on most images. Fig. 4 shows a

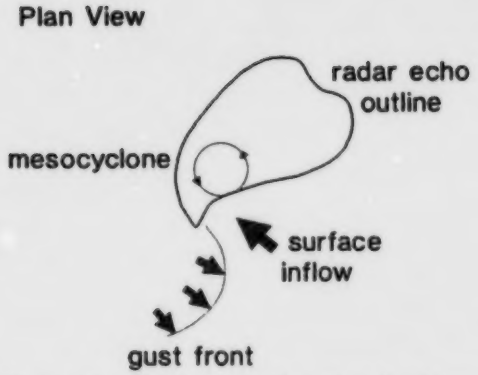

Figure 4: Plan view of a thunderstorm with associated features.

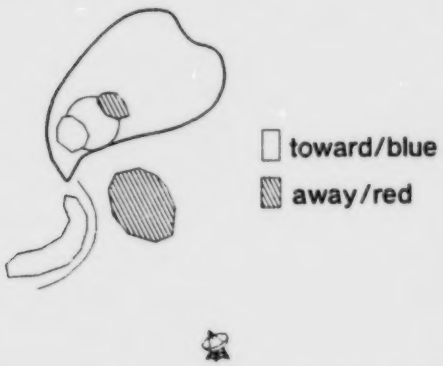

Figure 5: Radial velocity pattern for Fig. 4

plan view of a thunderstorm radar echo with a mesocyclone, surface inflow and gust front. Fig. 5 shows the radial velocity pattern that might be observed with the indicated radar position. The circle drawn within the boundary of the radar echo is where the mesocyclone is expected. Regardless of the position of the radar, the radial velocity pattern of rotation is indicated by small areas or patches of away and toward velocities.

> Aside: Doppler radar imagery is usually displayed in colour. Generally, warm or red hues are used to denote receding targets and cool or blue hues are use for approaching targets. An acronym RABT (pronounced rabbit) meaning *R*ed *A*way *B*lue *T*owards may be helpful in remembering the colour scheme.

The tornado with a typical diameter of 0.5 km may be identified with a similar but much smaller radial velocity pattern. However, because of its small dimension, unless it is close to the radar (< 60 km), the tornado is unlikely to straddle adjacent radar radials 1° apart and therefore to produce this recognizable pattern. A tornado totally encompassed by a radar beam will produce on average, a zero velocity data point with high spectral width (standard deviation of the velocity spectrum). Depending on the signal processing filters, this data point may be discarded in the processing.

3.3 Gust Fronts/Convergence Patterns

Fig. 4 and 5 also illustrate the expected velocity pattern one would expect with a gust front or a region of convergence for the indicated radar position. The pattern to look for is an area of locally enhanced velocity. However, if the gust front is lying such that the wind gust vectors are perpendicular to the radar radial then this pattern is not observed.

These figures also illustrate that the surface inflow-gust front region can show the same pattern as rotation. The difference from rotation can not be resolved without resorting to a conceptual model of a thunderstorm flow field pattern. The mesocyclone is expected to be found within the heart of the thunderstorm. The inflow-gust front pattern is expected at the edge of the strongest reflectivity and is also generally larger in size and weaker in shear than the mesocyclone. The gust front is also only found near the ground. Gust front tornadoes

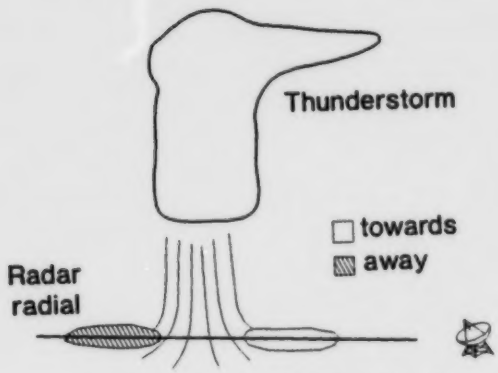

Figure 6: Schematic of a downburst.

(gustnadoes) can confound this picture because of their low reflectivity and location on the periphery of a thunderstorm. They also originate at the surface and evolve upwards with time, so a mesocyclone might not be observed. When the gust front is lined up along a radial, it may be identifiable by a line of weak azimuthal shear.

3.4 Downbursts

Downbursts (macro or micro) are illustrated in Fig. 6. They are generally low level phenomena (below 300 m) and are therefore observable only if positioned close to the radar since the radar beam rises relative to a curved Earth. They are identified by a divergence pattern, a small couplet of away and toward velocities lined up along a radar radial. The downburst signatures can be identified regardless of the radar position because of its axial symmetry.

3.5 Complications

The brief discussions above are idealized and in practice the actual patterns may be complicated by asymmetry of the features and convergence, divergence and rotation of the wind fields around them. Another factor is storm motion which adds a constant to the radial velocities. Therefore, rotation signatures are identified by a radial velocity couplet where the toward and away velocities may not be symmetric about zero.

Another complication occurs when airflows due to several systems interact; for example, a cold front and an extratropical storm.

4. Summary

This laboratory will illustrate a few nowcasting applications of Doppler radar emphasizing radial velocity image interpretation rather than the use of automatic interpretation and detection algorithms. Hopefully, the participant will leave with a better understanding of:

- Doppler radar radial velocity interpretation.
- the necessity to have a conceptual model of the airflow to aid in interpretation.
- the necessity of seeing more than one type of imagery (that is, reflectivity, radial velocity and perhaps spectral width) to aid interpretation.
- the additional aid that Doppler radar can provide in the forecasting of weather in all seasons.
- the necessity to continue to observe, study and develop conceptual kinematic models of mesoscale precipitation systems. Not enough is known about the complex airflows in these systems.
- the role of automated objective algorithms. They make a major contribution but they can not do the entire job because similar radial velocity fields can be produced from several flow fields. The real value of

the automated detection algorithms is that they focus the attention of the forecaster to specific areas of the radar image.

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OPERATIONAL ATMOSPHERIC DISPERSION FORECASTING

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Abstract - Over the past few years, concerns about the state of the environment have grown remarkably. The reduction of visibility caused by smoke from forestry and agricultural activities, health concerns over emissions from residential woodstoves and levels of pollution in our urban centres are important environmental issues. The Atmospheric Environment Service provides an operational air quality service in a few areas of Canada, mainly to support the forest industry. In order to deal with these other environmental issues, the AES may be required to expand the air quality services program.

A successful air quality services program is highly dependent on an operational capability to predict atmospheric dispersion. Meteorologists working in an operational environment already possess the scientific knowledge and tools to prepare such a forecast. These tools and the associated knowledge must be tailored and applied to the atmospheric dispersion problem.

Important meteorological processes fundamental to atmospheric dispersion are reviewed with special emphasis on existing operational techniques and procedures. The focus of the paper is to develop a 'check-list' to assist the operational meteorologist in analyzing and forecasting the dispersive capability of the atmosphere.

Résumé - Depuis les dernières années, l'intérêt pour l'état de l'environnement a augmenté considérablement. La réduction de la visibilité causée par l'activité forestière et agricole, l'effet des émissions de fours à bois résidentiels sur la santé et le niveau de pollution de nos centres urbains sont des questions environnementales importantes. Le service d'environnement atmosphérique fournit déjà un service opérationnel de qualité de l'air dans certaines régions du Canada, principalement a titre d'assistance a l'industrie de la fôret. Afin de soutenir une plus grande variété de programmes, le SEA devra peut être élargir son programme de qualité de l'air.

Un programme adéquat du service de la qualité de l'air dépend très fortement de la capacité opérationnelle de prédire la diffusion atmosphérique. Les météorologistes qui travaillent dans le secteur opérationnel possèdent la connaissance scientifique et les outils pour préparer une telle prévision. Ces outils et connaissances doivent être adaptés et appliqués au problème de la diffusion atmosphérique.

D'importants processus météorologiques, fondamentales à la diffusion atmosphérique, sont revus avec une attention toute spéciale accordée aux techniques et procédures déjà existantes. Cet article se concentre sur le développement d'une liste pour guider le météorologiste opérationnel dans l'analyse et la prévision de la capacité de diffusion de l'atmosphère.

INTRODUCTION

The scientific knowledge and tools to prepare a dispersion-potential forecast already exist in the operational environment. These tools and the associated knowledge must be tailored and applied to the atmospheric dispersion problem.

The important meteorological aspects of atmospheric dispersion, with special emphasis on existing operational techniques and procedures, are reviewed. The primary focus will be to assist the operational meteorologist in analyzing the present dispersive capability of the atmosphere and then, using a 'check-list' approach, forecast changes for the next day.

ATMOSPHERIC DISPERSION

In the atmosphere, dispersion is the three-dimensional spreading of air parcels and associated airborne pollutants. The turbulent motion of the lower atmosphere is a major factor in the dispersion process. Turbulence, or the ensemble of turbulent eddies, carries the pollution away from or towards the underlying surface (Seinfeld, 1986).

The depth of the turbulent layer defines the portion of the lower atmosphere of interest in the study of dispersion processes (Wyngaard, 1988). This turbulent layer is often referred to as the Planetary Boundary Layer (PBL) or the mixed layer.

METEOROLOGICAL CONTROLS

In order to describe, analyze and predict atmospheric dispersion, the meteorological controls in the lower layers of the atmosphere must be considered. These include winds, lapse rates and local circulation patterns.

Wind

The turbulence generated by the wind is an important factor in describing the dispersion potential in the lower atmosphere. Air flowing over rough terrain will generate small scale eddies (forced convection) regardless of the stability. As the lower layers become more unstable, these eddies can grow and disperse pollutants more efficiently. Generally, the higher the wind speed the better the atmospheric dispersion. Wind direction is also important. The horizontal variation of the wind direction, or the meander, will cause pollutants to disperse (Oke, 1987).

Lapse Rates

In the absence of strong winds, the dispersion potential of a stable* atmosphere is low since pollutants will tend to remain near the ground. Unstable or neutral conditions, generated by surface warming (diurnal heating or cold air advection over a warm surface), often create turbulent eddies capable of distributing and therefore diluting pollutants throughout the unstable layer.

Temperature inversions which 'cap' the mixed layer define the top of the vertical mixing. Inversions result from radiational cooling, subsidence and the advection of warm air over cool surfaces. Operational meteorologists are familiar with these conditions as they are encountered regularly in the preparation of weather analyses and forecasts.

When atmospheric dispersion is being forecast, the spatial and temporal extent of inversions is another important aspect. The diurnal cycle of nocturnal inversion formation in the late afternoon, intensification during the night and subsequent weakening or destruction the following day provides a reasonable guide of the expected dispersion characteristics for the period. However, when an area of high pressure becomes stationary over the area and persists for a week or more, the dispersion capability of the atmosphere changes, deteriorating day by day. A similar situation occurs with the movement of a very cold airmass into a region. The cold air can pool and remain in low lying areas for days creating very poor dispersion conditions.

Local Circulation Patterns

Land and sea (lake) breezes, mountain and valley flows will significantly alter the low level dispersion. A diurnal circulation pattern often develops which will move air parcels up and down the mountain slopes as well as along the valleys. Generally this circulation will have short term effects on the dispersion where pollution is moved from one area to another or is mixed throughout the valley. The addition of an inversion however changes the situation significantly. A nocturnal inversion in a valley seriously limits the extent to which the airborne pollution can be dispersed. The inversion will trap and concentrate the pollution. Even during the breakup of nocturnal inversions, flows from the slopes will cause a further slumping of the inversion and limit dispersion even more. The simple effect of channelling must also be considered as pollution at one end of the valley is directed toward other areas within the valley by the local wind patterns.

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* A stable atmosphere is here defined as one in which the lapse rate in the lower levels is significantly less than dry adiabatic. An unstable atmosphere is one in which the lapse rate equals or is close to dry adiabatic.

Land and sea (lake) breeze circulations are also very important. These thermal circulation patterns are usually associated with summer anticyclonic systems, nearly clear skies and weak synoptic winds. Cool marine air moving onshore creates a strong low level inversion during the day which will often lower as the circulation strengthens during the afternoon.

ESTIMATING ATMOSPHERIC DISPERSION

Dispersion of airborne pollutants originating at the surface depends primarily on two conditions: the depth of the mixing layer and the strength and direction of the winds or the turbulence through this layer. Operationally the depth of the mixed layer and the winds in this layer can be estimated by using one or more of: tephigram, satellite imagery, synoptic analysis.

Tephigram

This is the most direct method of measuring the mixing depth. The disadvantage is that data are collected only from scattered radiosonde locations twice daily. Forecasts of vertical temperature profiles can be approximated at other locations, however, by adjusting the profile of a representative radiosonde site. From these forecast temperature profiles, estimates of mixing depths can be made for different times of the day (Holzworth, 1972). The main challenge to this approach is often choosing the most representative vertical temperature profile for a particular location when it is too far from any radiosonde site or is midway between two radiosonde sites in different airmasses. Forecasting a vertical temperature and moisture profile usually entails one or more of:

a) frontal analysis to determine in which airmass the location in question will be over the next several hours, and choosing the appropriate radiosonde site,

b) adjusting for any vertical temperature and moisture differences between this location and the distant radiosonde site to reflect differences in temperature and moisture,

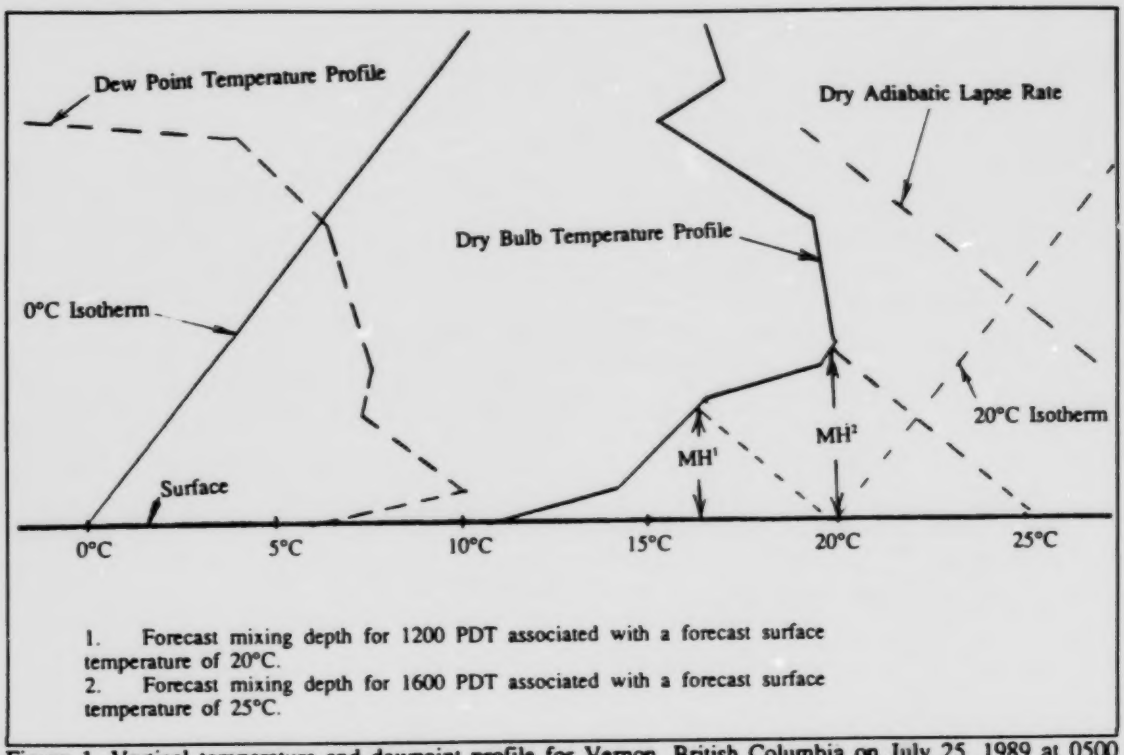
c) correcting for any temperature advection that is likely to occur over the next 24 hours and,

d) adjust for surface temperature and moisture differences due to local effects.

If the radiosonde site is at a lower elevation than the location needing a dispersion forecast, the "below ground" portion of the temperature profile can be ignored. If the radiosonde is higher than the location needing the forecast (which is not usually the case), an estimate of the profile in the lowest levels must be made.

In general, mixing depths fall to near zero after sunset as a layer of cool air forms near the surface, stopping free convection. After sunrise, increasing surface temperatures lead to an increase in the mixing depth. In figure 2, a diurnal temperature forecast is used to predict changes to the 0500 PDT September 25, 1989 vertical temperature profile at Vernon, B.C. which is then used to forecast the mixing depth at 1200 and 1600 PDT. Vertical motion and horizontal temperature advection are assumed to be negligible.

Wind speeds in the mixed layer can be estimated by averaging the observed surface and upper winds through the layer. Since these vary substantially as diurnal heating occurs, a better approximation for the mixed-layer winds later in the day is usually the geostrophic wind at the surface.



1. Forecast mixing depth for 1200 PDT associated with a forecast surface temperature of 20°C.
2. Forecast mixing depth for 1600 PDT associated with a forecast surface temperature of 25°C.

Figure 1. Vertical temperature and dewpoint profile for Vernon, British Columbia on July 25, 1989 at 0500 PDT. Superimposed on the profile are expected mixing depths for 1200 PDT and 1600 PDT.

Satellite Imagery

This is a more indirect method of determining mixing depth and accompanying winds, but it has the advantage of providing more detailed information in space and time (during daylight hours). An estimate of the mixing depth can be made by determining the low level atmospheric stability, which in turn can be estimated by the cloud type. Table I gives an estimate of the mixing depths that might be associated with certain low level cloud types and whether a capping inversion is present. Of course, a forecast of any of these cloud types would imply a corresponding forecast of mixing depth.

Low level winds can also be estimated from satellite imagery by measuring the distance travelled by individual cloud elements. This approach is restricted, however, to unstable situations when the mixing depth is unlimited and atmospheric dispersion is not a problem.

Synoptic Analysis

Analysis of the synoptic weather pattern can be used to estimate the mixing depth and associated winds. Areas under the influence of persistent upper and/or surface ridges are probably stable due to subsidence and likely have inversions present. Without the aid of significant diurnal heating, such areas probably have low mixing depths. If the surface geostrophic winds are light, which is often the case in such synoptic situations, the potential for dispersion is therefore probably poor. This would contrast to areas under the influence of an upper and/or surface low centre or trough which likely has relatively unstable air, large mixing depths, stronger winds and good dispersion potential. A warm front or trowal associated with an upper trough may introduce stability to the airmass and lower the mixing depth. However, if the weather system is vigorous enough, low level winds in the mixed

Table I Estimates of mixing depths associated with some low level (non-frontal) cloud types. Dispersion estimates are for situations involving light winds in the mixing layer.

CLOUD TYPE	CAPPING INVERSION PRESENT?	MIXING DEPTH (Approximately)	DISPERSION ESTIMATE
1. Fog	Yes	0-1000 feet	Poor
2. ST	Probably	0-2000 feet	Poor
3. SC	Possibly	Top of SC layer, about 5000 ft.	Fair
4. CU	Unlikely below 5000 ft	5000-8000 feet	Good/Excellent
5. TCU/CB	Unlikely	Unlimited	Excellent

layer will likely be strong enough to improve dispersion. The movement of a cold front through the area of interest will likely create good dispersion conditions due to the post frontal winds and subsequent turbulence. The upward movement of the warm polluted air over the cold front will also have a major impact on the local air quality. Other influences on the dispersive capability of the atmosphere include:

1. marine inversions caused by an onshore flow of cool air will reduce the mixing depth and the dispersion

2. large scale warm air advection over a cool surface will generally reduce the mixing depth due to the stabilization of the airmass, while the opposite is true for cold air advection over a warm surface, particularly in summer

3. katabatic winds will reduce mixing depths but the increase in wind speed through the mixed layer will improve local dispersion

4. diurnal land and sea (lake) breezes can reduce the mixing depth in the afternoon over coastal areas, though this may be compensated for with increased wind speeds. Pollutants will also tend to be advected inland in the afternoon (in the low levels).

DISPERSION FORECAST CHECKLIST

The first step in analyzing the current dispersive capability of the atmosphere is to determine the depth of the mixed layer and the turbulence within that layer. The following is a check-list to assist in this analysis:

1. Complete a surface synoptic analysis of the area of interest making note of high pressure areas, fronts and wind patterns.

2. Consult upper air charts for a general assessment of the synoptic stability. Look for indications of vertical motion and the position of upper ridges and troughs. Note the temperature, moisture and wind patterns at 85 kpa to assist with modifications to upper air ascents as required.

3. Using an upper ascent that is most representative of the synoptic situation over the area of interest, calculate the depth of the mixed layer. This ascent may require modifications to account for local weather and topographic conditions.

4. Assess the topography of the area making note of local circulation patterns and inversion conditions that might effect the potential for atmospheric dispersion.

5. Look for the presence of local conditions that indicate or verify the calculated mixing height. Cloud layers, vertical wind shear, existing pollution may provide guidance.

6. Determine the strength and direction of the wind field within the mixed layer.

Forecasting the dispersion potential requires answering the following questions:

1. What changes will there be to the current surface synoptic situation; frontal passages, advection, change in wind direction or speed?

2. If changes are occurring what will be the effect on the analyzed stability and mixing depth?

3. Will the movement of upper air patterns effect the vertical motion field?

4. Are local circulation patterns going to change, land and sea (lake) breeze, valley flow?

Once a forecast of the mixing depth and the average winds through the mixed layer is made, the dispersion potential can be estimated. Table 2 gives an approximation of this dispersion potential.

Table II. An approximate relation between the dispersion capacity of the atmosphere, the mixing depth and the average winds through the mixed layer.

MIXING DEPTH	0-1000	1500-2500	3000-5000	5000+ (feet)
WINDS (knots)				
Light 0-5	poor	poor/fair	fair	fair/good
Moderate 10-15	fair	fair/good	good	excellent
Strong 20+	fair/good	excellent	excellent	excellent

SUMMARY AND CONCLUSIONS

The growing concern over the state of the environment has and will create opportunities for the Atmospheric Environment Service to expand into new areas of applied meteorology. Analyzing and predicting the capability of the lower atmosphere to disperse pollutants will become one of these new areas of interest.

The use of detailed synoptic meteorological analysis methods currently applied in operational weather offices provide all the information that is required to provide estimates of atmospheric dispersion. Concepts of inversion heights, mixing depths and vertical wind profiles are common to operational meteorologists. Turbulence and its effects on the movement of air parcels is dealt with daily associated with aviation services. What must be done is to encourage meteorologists to view the lower portion of the atmosphere in a slightly different manner and consider how these common concepts can be applied to the description and prediction of atmospheric dispersion.

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THE OPERATIONAL USE OF A HIGH SPEED INTERACTIVE RADAR DATA PROCESSING SYSTEM - RDPS

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H4M 2N8

Summary

A prototype Radar Data Processing System has been in use at the Centre Météorologique du Québec (CMQ) for the past two years. This system allows real-time reception and processing of full volumetric data from the McGill radar at 5 minute intervals for use by operational meteorologists, thus providing them with a powerfull tool to analyse and display radar data in multiple ways and to produce short-term forecasts.

Résumé

Le prototype d'un système de traitement de données radar est utilisé depuis deux ans au Centre Météorologique du Québec (CMQ). Ce système permet la réception et le traitement des données volumétriques qui parviennent du radar de l'université McGill à toutes les 5 minutes. Il fournit aux météorologistes opérationnels un outil puissant pour l'analyse et l'affichage des données radar sous de multiples formes et pour produire des prévisions à court-terme.

1. INTRODUCTION

The McGill Radar Weather Observatory developed, for the Canadian Atmospheric Environment Service, a Radar Data Processing System (RDPS) designed to provide operational meteorologists with a powerfull, user-friendly tool to detect and forecast all types of precipitation and particularly severe thunderstorms. The system is described in Austin et al. (1), and the prototype is currently in use at the Centre Météorologique du Québec in Montréal.

This paper will briefly describe how this system is used in weather forecast operations.

2. THE DATA

Datasets come from the McGill University radar (10 cm wavelength, 0.8 degree beamwidth, 10 m diameter antenna) and consists of a volume scan of 24 elevation angles up to a range of 240 km, and up to 480 km for the lowest elevation angle.

A new volume of data is transmitted every five minutes to the weather centre and stored on disc. The Product Processing System (PPS) runs on a MV-4000 Data General computer and is used to generate a wide range of products that are displayed on a high resolution colour monitor.

3. OPERATIONAL USE OF RDPS

Radar data are incorporated into the everyday forecast programs at CMQ. With RDPS, meteorologists have access to numerous radar outputs every 5 minutes; the horizontal products have a spatial resolution of 1 x 1 km up to 120 km from the radar and 2 x 2 km from 120 to 240 km.

For more than 15 years CAPPI's have been considered the basic operational products used for radar display; Echo Tops (showing the highest tops of precipitation over each cartesian point), accumulation maps and forecasts (SHARP algorithm, Bellon et al. (2)) are other products used on a routine basis.

The system has been designed to automatically generate specific products after reception of each volume scan; the schedule of such products can be set by users depending upon the season of the year, weather type, etc. Table 1 shows a typical summer operational schedule of automatically generated products.

TABLE 1. Operational schedule for RDPS automatic product generation

every 5 minutes:	1.5 or 3km CAPPI 5 km CAPPI 7 km CAPPI Echo Tops - 18 dBZ threshold Echo Tops - 40 dBZ threshold
every half-hour	Forecast CAPPI Point forecast for 16 locations Long Range (to 480 km)
every hour	Accumulation Forecast Accumulation (for the next 2 hours) TIMMAXR - location of highest reflectivities over each cartesian point for the past "x" hours.

In addition, RDPS can generate other products requested interactively by users such as vertical cross-sections, CAPPI's at different heights, point forecasts, etc. Finally the display system allows fast animation of radar echos, zooming, panning, look-up table selection and modification, geographic overlay selection, statistics over a given area of precipitation, etc.

4. SEVERE WEATHER DETECTION

RDPS is an excellent tool for "ordinary" precipitation events but its potential is fully revealed during severe convective situations.

Several studies have shown that severe thunderstorms have a distinctive structure; in particular, the reflectivity distribution in the cell at all levels is an important characteristic in identifying a severe storm; the overhanging of mid-level reflectivity core associated with a weak echo region underneath is a good example of a distribution generally associated with severe weather. Access to volumetric radar data becomes essential to weather forecast operations since it allows meteorologists to display and study data in such a way as to easily identify and pinpoint specific patterns related to severe weather.

The capability of RDPS to generate several CAPPI's every five minutes proved to be extremely usefull to CMQ meteorologists. Looking at the precipitation at a constant level is a much better way than looking at PPI's, where the height of echoes increases with range. Moreover, as shown in recent studies, it is at mid-levels that organization of reflectivities will first exhibit a potential for severe weather. A CAPPI at 7 km is thus an easy and accurate way to detect reflectivity cores, precursors of severe thunderstorms and this, over the entire radar coverage area.

As an example, fig. 1 and 2 show the 1.5 and 7 km CAPPI's for August 3, 1988 at 2110 UTC. The area indicated by the arrow on the 1.5 Km CAPPI (fig. 1) shows no evidence of any significant echo pattern. However on the 7 km CAPPI (fig. 2) one can already see a well defined circular cell with intensities of 100 mm/h or 55 dBZ. 40 to 50 minutes later, this storm produced 2-4 cm hail and winds in excess of 100 km/h, causing heavy damage over the Montréal area.

In order to discriminate between different types of severe events, one must consider the whole structure of the precipitation volume. Large hail will be associated most often with supercells showing an overhang with very high reflectivities; the vertical cross-section of a hailstorm that occured over Montréal on May 29, 1987 is a good example of a supercell (fig. 3); heavy rain however will show as a vertical column with the highest intensities located mostly in the lower part of the storm. "Solid" walls of reflectivities , having very often a crescent or arc shape or even a spiral shape will most certainly be precursors of strong winds on the ground.

RDPS is designed specifically to give the forecasters the possibility to do such an in-depth study of storms and thereafter issue timely and accurate warnings for the threatened regions.

With RDPS forecasters can also request short term (1 to 5 hours) forecasts of CAPPI's. For severe thunderstorms wich deviate from the mean flow, the system allows the meteorologist to input a new displacement vector and get a new forecast. At the same time, point forecasts can be generated for specific locations such as airports or cities; these forecasts will give the time of occurence of precipitation and the total possible accumulation based on intensities and the assigned Z-R relationship.

Animation of precipitation echoes allows forecasters to constantly monitor the propagation and the evolution of severe thunderstorms cells.

5. CONCLUSION

A Radar Data Processing System was developed by the McGill Radar Weather Observatory and the prototype is currently used operationally at the Centre Météorologique du Québec. Operational use proved that RDPS is a powerfull and user-friendly tool allowing meteorologists to perform an in-depth study of precipitation volumes and particularly of severe thunderstorms. As our knowledge of severe storms increases, access to volumetric radar data becomes essential to operational meteorologists. RDPS is a superb example of what can be done to use radar data to their maximum benefit.

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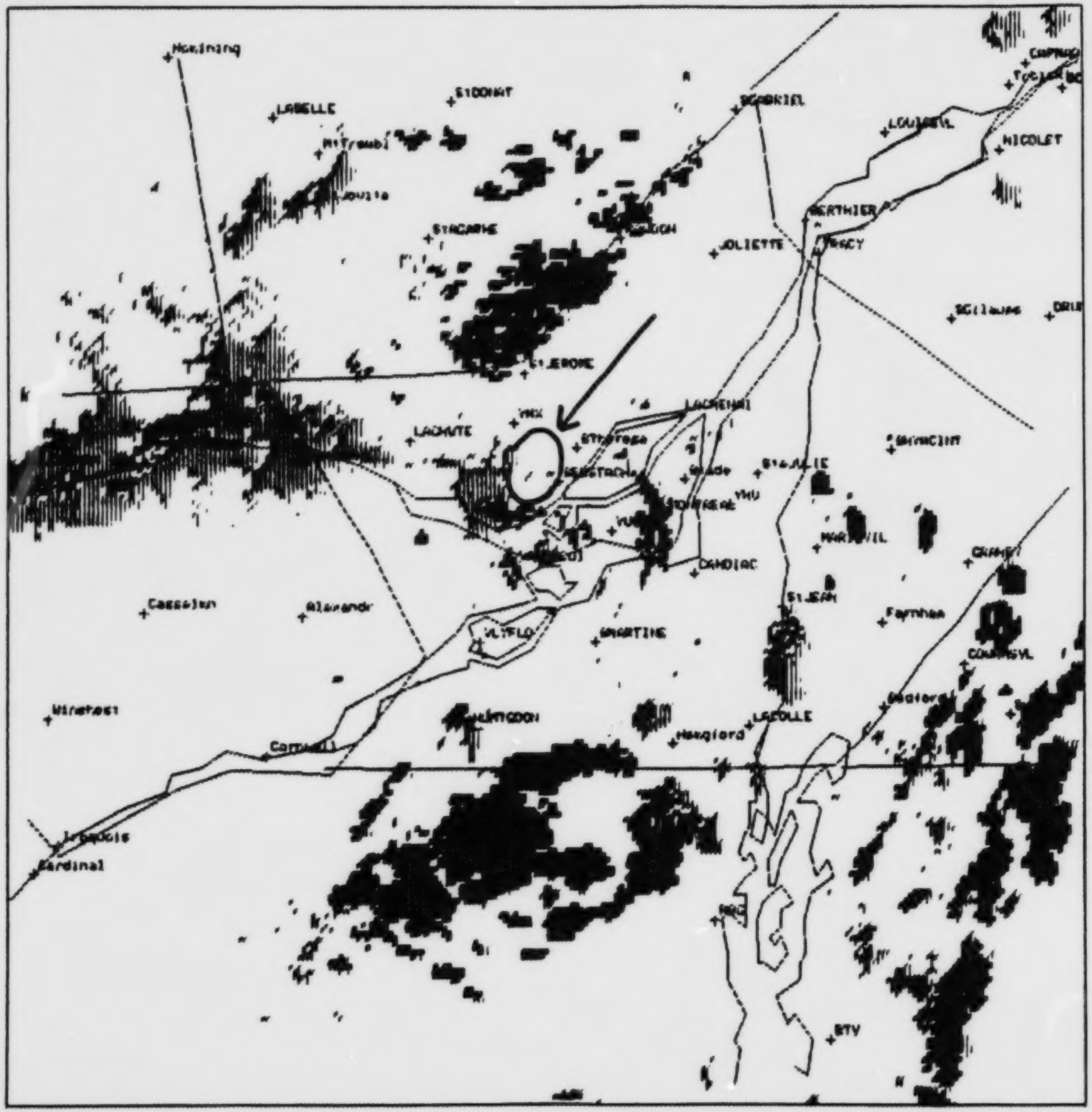
MCG 1.5 KM CAPPI 88-08-03 ZR:RAIN A=0200,B=1.6 FIX RNG/RES:S/H
ALG: AVGE

21:10 Z

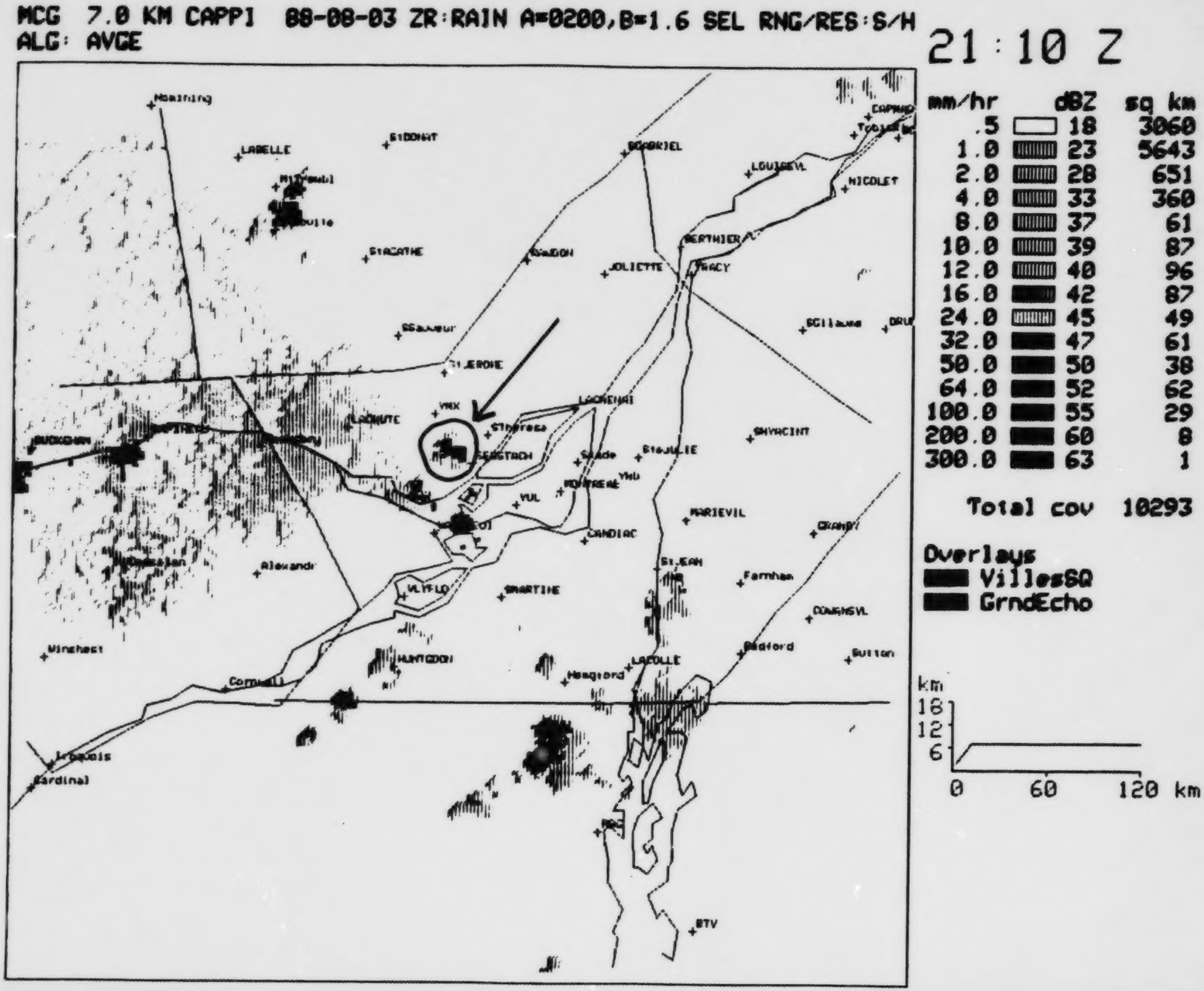


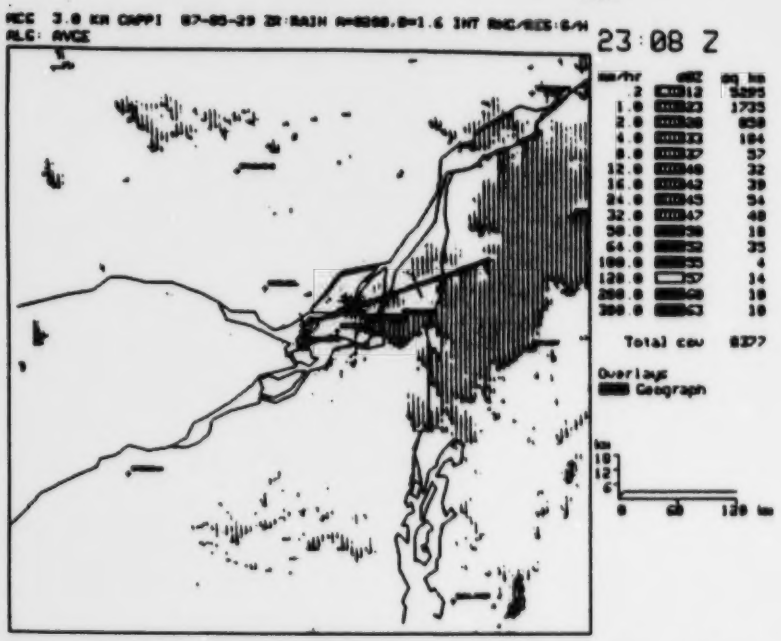
mm/hr	dBZ	sq km
.5	18	1617
1.0	23	1529
2.0	28	847
4.0	33	684
8.0	37	129
10.0	39	170
12.0	40	146
16.0	42	160
24.0	45	128
32.0	47	150
50.0	50	33
64.0	52	64
100.0	55	39
200.0	60	15
300.0	63	14

Total cov 5725

Overlays
VillesSQ
GrndEcho

km
18
12
6
0 60 120 km


MCG 7.0 KM CAPPI 88-08-03 ZR:RAIN A=0200,B=1.6 SEL RNG/RES:S/H
ALG: AVGE
21:10 Z
mm/hr dBZ sq km
.5 18 3060
1.0 23 5643
2.0 28 651
4.0 33 360
8.0 37 61
10.0 39 87
12.0 40 96
16.0 42 87
24.0 45 49
32.0 47 61
50.0 50 38
64.0 52 62
100.0 55 29
200.0 60 8
300.0 63 1
Total cov 10293
Overlays
VillesSQ
GrndEcho
km
18
12
6
0
60
120 km
LABELLE
JOLIETTE
BERTHIER
NICOLET
LACHENAI
MARIEVIL
CANDIAC
YUL
Farnham
Bedford
Sutton
BTV
Winchest
Cornwall
Cardinal
Alexandr
HUNTGDON
SMARTINE
LACOLLE
Hemgford
LOUISEVL
SHYACINT
COWANSVL
GRANBY

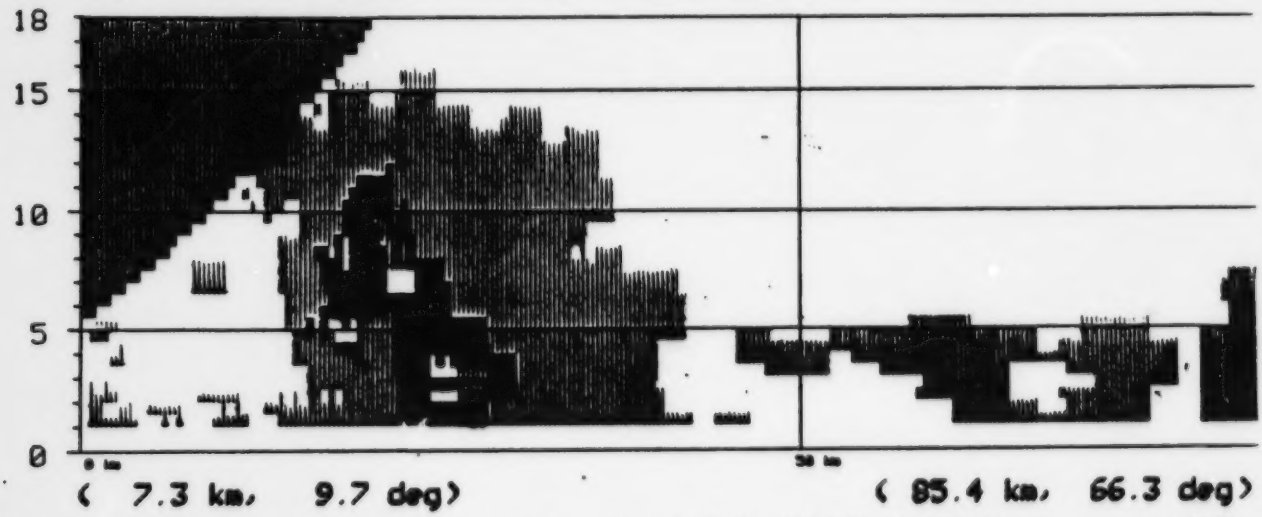


23:08 Z

mm/hr	dBZ
.2	12
1.0	23
2.0	28
4.0	33
8.0	37
12.0	40
16.0	42
24.0	45
32.0	47
50.0	50
64.0	52
100.0	55
128.0	57
200.0	60
300.0	63

No Data

MCG VERT X-SECT 87-05-29 ZR:RAIN A=0200,B=1.6 INT
ALG: AVGE CORRIDOR: 1.0 KM HORIZONTAL RES. = 1.0 KM



(7.3 km, 9.7 deg) (85.4 km, 66.3 deg)

ETUDE STATISTIQUE DU MODELE REGIONAL CANADIEN AUX ELEMENTS FINIS (CDNEFR)

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RESUME.

Une étude statistique du modèle régional canadien aux éléments finis, faite à la résolution du modèle, soit 100 km, et sur la période du 1 janvier 1989 au 30 juin 1989, démontre une nette tendance à l'affaissement des hauteurs géopotentielles et à l'abaissement des températures, au cours de l'intégration du modèle. Ceci s'accompagne d'un net accroissement de l'humidité spécifique.

La conformité interne du modèle aux éléments finis est très bonne. Le mouvement vertical a une structure verticale, qui apparaît, en moyenne, physiquement acceptable, et le mouvement vertical ascendant correspond généralement à une convergence dans les bas niveaux et à une divergence en altitude. Les prévisions du mouvement vertical correspondent bien aux prévisions de zéro heure valides au même temps, et celui-ci ressort comme étant un bon outil prévisionnel pour les quantités de précipitations, du moins un outil de beaucoup supérieur aux advections du tourbillon.

A statistical study of the Canadian Regional Finite Element model, conducted at the same resolution as the model (100 km), from Janauary 1, 1989 to June 30 1989, shows that the model has a clear tendency to lower geopotential heights and temperatures during its integration. This is accompanied by a definite increase in specific humidity.

The internal consistency of the Finite Element model is very good. Vertical motion has a vertical structure taht appears to be physically acceptable, on average, and tising vertical motion generally corresponds to cenvergence at low levels and divergence aloft. Forecasts of vertical motion corresponds well with the zero-hour forecasts valid at the same time, and it is shown to be a good forecasting tool for precipitaion amounts, or at least a much better tool than vorticity advection.

1.0 INTRODUCTION.

Le modèle régional canadien aux éléments finis (CDNEFR) (Staniforth et Daley, 1979; Mailhot et Chouinard, 1989; Benoit et al, 1989; Tanguay et al, 1989) est le principal modèle numérique de simulation de l'atmosphère pour les prévisions à court terme utilisé dans le système canadien de prévisions météorologiques du Service de l'environnement atmosphérique. Le modèle CDNEFR est intégré jusqu'à 48 heures deux fois par jour, dans les cycles de production de 00 et de 12 TU du Centre météorologique canadien (CMC).

La présente étude veut examiner le comportement du modèle CDNEFR (version opérationnelle en janvier 1990) en adoptant une approche statistique. Elle se place donc sous la même ligne directrice que l'étude déjà publiée par Verret (1988), et a été faite dans le cadre d'un projet conjoint CMC-Formation professionnelle. Des résultats complets sont disponibles dans Verret et Patoine (1990).

2.0 APPROCHE STATISTIQUE.

Différents champs du modèle CDNEFR ont été extraits sur une grille de 66 X 46 points (3036 points), avec une résolution uniforme de 100 km. Cette grille d'extraction est en fait, une portion de la fenêtre centrale de la grille opérationnelle du modèle CDNEFR, dont la résolution

est de 100 km et couvre le Canada et le nord des Etats Unis. Les résultats présentés ici ont été compilés sur les deux cycles de production ensemble, 00 et 12 TU, ce qui masque tout cycle diurne qui pourrait être présent dans le modèle CDNEFR.

Les champs extraits sont: la pression au niveau moyen de la mer, les accumulations de précipitations sur 6 heures, les nuages bas, moyens et hauts, le taux instantané de précipitations, les hauteurs de différents niveaux de pression, les températures, les écarts du point de rosée, la divergence, le mouvement vertical, le tourbillon et les composantes U et V du vent. La plupart des champs ont été extraits à 1000, 850, 700, 500 et 250 hPa. Des champs supplémentaires ont aussi été calculés à partir des champs extraits, comme l'advection du tourbillon à 500 hPa par le vent thermique (épaisseurs 1000-500 hPa), l'advection de tourbillon, le laplacien de l'advection des températures et l'humidité relative. Tous les champs ont été extraits à partir des archives du CMC. La période couverte par l'étude s'étend du 1 janvier 1989 au 30 juin 1989.

Les moyennes des champs extraits ont été calculées selon le temps de projection. Les corrélations de différents champs entre eux (corrélations croisées) ont été calculées à toutes les 12 heures entre zéro et 48 heures. Finalement, les champs ont été interpollés à 264 stations canadiennes, et les corrélations entre les champs interpollés et les observations de quantités de précipitations sur six heures ont été calculées. Le temps de validité des champs prévus par le modèle à des temps spécifiques correspond à la fin de la période de six heures sur laquelle les quantités de précipitations sont observées.

Près de 900,000 données aux points de grille, ont été utilisées pour calculer les statistiques présentées ici. Environ 50,000 observations ont été considérées pour calculer les corrélations entre les champs prévus par le modèle et les observations de quantités de précipitations.

3.0 RESULTATS.

Les résultats de l'étude statistique sont présentés selon trois thèmes principaux: a) l'évolution du modèle CDNEFR sur 48 heures, établie à partir des moyennes des champs à chaque 12 heures entre 0 et 48 heures; b) la conformité interne du modèle CDNEFR, basée sur les corrélations croisées de différents champs; c) la validité des prévisions du modèle CDNEFR, étudiée à partir des corrélations entre les champs du modèle et les observations de quantités de précipitations sur six heures. A la fin de la section 3.0, un résumé des principaux points sera présenté.

3.1 EVOLUTION SUR 48 HEURES.

La figure 1 montre l'évolution sur 48 heures des hauteurs géopotentielles (dam) des niveaux 1000, 850, 700, 500 et 250 hPa, des températures (°C), de l'écart du point de rosée (°C) et du taux instantané de précipitations (mm/h). 120, 260, 500 et 960 dam ont été soustraits des hauteurs géopotentielles des niveaux 850, 700, 500 et 250 hPa respectivement. 10°C ont été ajoutés aux températures à 250 hPa.

Les hauteurs géopotentielles à tous les niveaux diminuent de façon linéaire au cours de l'intégration du modèle CDNEFR. Cette chûte des hauteurs peut être considérée comme une perte de masse, sur la grille d'extraction utilisé ici, couvrant le Canada et le nord des Etats Unis. Cependant la chûte des hauteurs est plus prononcée en haute altitude que dans la basse troposphère. Les épaisseurs partielles de bas niveaux sont conservées au cours de l'intégration du modèle, mais il y a un refroidissement global du modèle en haute atmosphère.

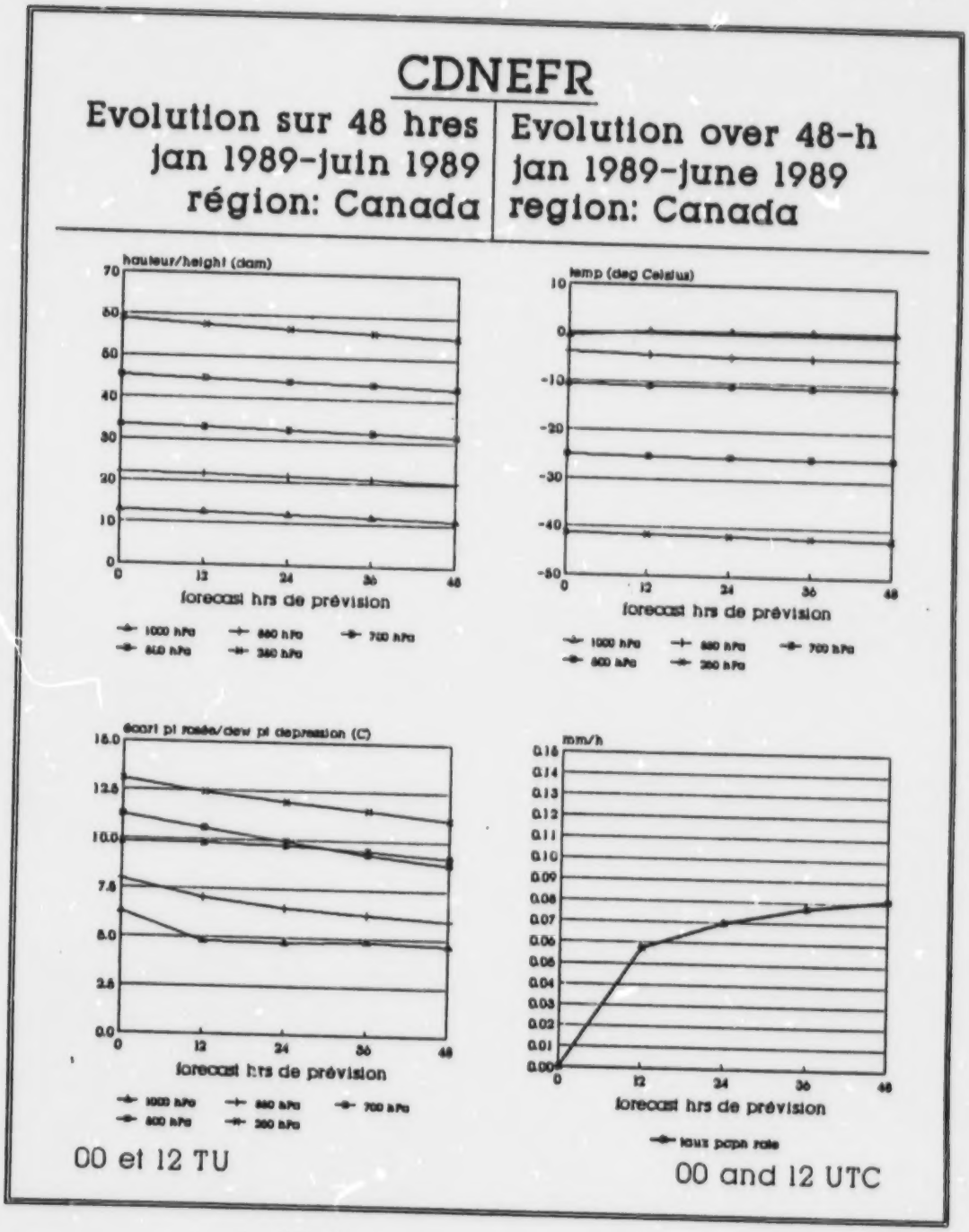

Figure 1: Evolution sur 48 heures des hauteurs géopotentielles, des températures, de l'écart du point de rosée et du taux instantané de précipitations. Les niveaux de 1000, 850, 700, 500 et 250 hPa sont considérés ici. 120, 260, 500 et 960 ont été soustraits des hauteurs des niveaux 850, 700, 500 et 250 hPa respectivement. 10°C ont été ajoutés aux températures à 250 hPa.

Les températures sont généralement conservées dans la basse troposphère (niveaux de 850 et 700 hPa), mais il y a un certain refroidissement aux niveaux de 500 et 250 hPa. Les températures à 1000 hPa semblent s'élever au cours de l'intégration du modèle CDNEFR. Cette accroissement des températures dans les bas niveaux se fait surtout dans les premières douze heures d'intégration du modèle. Il faut cependant faire attention aux champs extraits à 1000 hPa, ceux-ci étant souvent le résultat d'extrapollation.

Le modèle CDNEFR montre une chûte de l'écart du point de rosée partout sur la grille d'extraction. La chûte de l'écart du point de rosée est plus prononcée que ne l'est l'abaissement des températures. Le comportement de l'écart du point de rosée à 700 hPa fait cependant exception, avec une diminution moins prononcée qu'aux autres niveaux de pression.

Le taux instantané de précipitations, qui est toujours zéro pour une prévision de zéro heure, augmente rapidement dans les premières douze heures d'intégration. Ce comportement est fortement relié au problème de "spin-up", commun dans la plupart des modèles numériques connus: le modèle doit générer les précipitations au début de l'intégration. Cet ajustement du modèle se fait généralement sur les premières six ou douze heures d'intégration. Le taux de précipitations continue d'augmenter après les premières douze heures, mais avec une nette tendance à la stabilisation.

3.2 CONFORMITE INTERNE DU MODELE.

L'étude de la conformité interne du modèle présentée ici touche particulièrement le mouvement vertical prévu à 24 heures. Cependant des résultats identiques sont obtenus, quelque soit l'intervalle de prévision entre zéro et 48 heures, ce qui indique une excellente stabilité du modèle CDNEFR dans le temps.

La figure 2 présente les corrélations croisées du mouvement vertical à 1000, 850, 700, 500 et 250 hPa, et de la divergence à 850 et 300 hPa, pour des prévisions de 24 heures. Le mouvement vertical ascendant est défini comme étant négatif. Il y a donc une structure vertical dans le mouvement vertical du modèle CDNEFR. Lorsque le mouvement vertical est ascendant à un certain niveau, il est aussi ascendant aux niveaux adjacents. Le mouvement vertical ascendant diminue d'intensité en s'éloignant du niveau où il est maximum. Finalement, le mouvement vertical ascendant correspond très bien à une convergence dans les bas niveaux et à une divergence en altitude.

La relation entre le mouvement vertical et l'advection du tourbillon est bonne. L'advection du tourbillon étant une mesure de la divergence, le mouvement vertical à un niveau donné, corrèle généralement bien avec l'advection de tourbillon aux niveaux plus élevés.

Le laplacien de l'advection des températures peut être considéré comme étant un élément contributeur au mouvement vertical. Les corrélations entre ces deux champs est quelque peu décevante, étant de l'ordre de 0.3. Le laplacien de l'advection des températures est peut-être un élément important contribuant à augmenter le mouvement vertical dans des systèmes synoptiques bien organisés, mais pris globalement sur une grande supericie et sur une longue période temporelle, sa contribution au mouvement vertical est faible.

Il existe une bonne relation dans le modèle CDNEFR, entre le mouvement vertical et l'advection du tourbillon à 500 hPa par le vent thermique (épaisseurs 1000-500 hPa). D'autre part la relation entre le mouvement vertical et les quantités de précipitations prévues sur six heures et le taux instantané de précipitations est excellente. Il est à noter ici que le temps de validité du mouvement vertical correspond à la fin de la période de six heures sur laquelle les précipitations sont prévues. De plus, la grande variance des champs implique que les corrélations soient faibles.

3.3 CORRELATION AVEC LES OBSERVATIONS.

Tous les champs extraits du modèle CDNEFR ont été interpollés à 264 stations canadiennes en utilisant une technique d'interpollation bi-cubique, afin de calculer les corrélations avec les observations de quantités de précipitations sur six heures. Il est à noter que le temps de validité des champs prévus par le modèle, correspond à la fin de la période de six heures sur laquelle les précipitations sont observées.

Les quantités de précipitations sur six heures, le taux instantané de précipitations, le mouvement vertical et l'humidité relative prévus par le modèle CDNEFR, sont les champs qui montrent les meilleures corrélations avec les observations de quantités de précipitations sur six heures. La corrélation entre les observations de précipitations et les prévisions de précipitations (quantités ou taux) varie généralement entre 0.5 à 12 heures et 0.3 à 48 heures. Les corrélations entre les observations de quantités de précipitations et le mouvement vertical prévu à 850, 700 ou 500 hPa augmente entre zéro et 12 heures, en réponse au problème de "spin-up", après quoi elles diminuent linéairement avec le temps de projection. Les corrélations se situent généralement entre 0.3 et 0.2. Quoique plus faible, il existe une certaine relation entre les observations de précipitations et l'humidité relative à 850 et 700 hPa. La correction du problème d'humidification du modèle CDNEFR relevé à la section 3.1 pourrait contribuer à améliorer cette relation.

Les corrélations entre les observations de quantités de précipitations sur six heures et l'advection du tourbillon est très faible. L'advection du tourbillon n'apparaît donc pas comme étant un bon outil pour prévoir les quantités de précipitations. Les précipitations prévues par le modèle et le mouvement vertical semblent d'autre part, être des guides prévisionnels utiles.

Les corrélations entre les observations de précipitations et l'advection du tourbillon à 500 hPa par le vent thermique est de l'ordre de 0.1, à tous les intervalles de prévision, ce qui montre que ce prédicteur peut difficilement servir d'outil prévisionnel. Aucune relation entre les prévisions du laplacien de l'advection des températures et les observations des quantités de précipitations n'a pu être décelée.

Les corrélations présentées à la section 3.3 peuvent paraître faibles. Il faut noter cependant, que les corrélations sont calculées avec des accumulations observées de précipitations, qui constituent un champ bruyant. De plus, le temps de validité des champs prévus par le modèle correspond à la fin de la période d'observation des accumulations de précipitations. Dans le contexte de l'étude faite ici, les valeurs absolues des corrélations ne sont pas importantes en soi. Ce qui est important, c'est qu'un signal puisse être clairement discerné parmi les corrélations calculées, et que ce signal puisse supporter les hypothèses avancées ici.

3.4 PRINCIPAUX POINTS.

Voici les principaux points tirés des résultats de l'exercice présenté aux sections 3.1 à 3.3:

1: Les hauteurs tombent lors de l'intégration du modèle CDNEFR sur 48 heures. Ce phénomène est plus important en haute altitude, et peut être associé à une perte de masse dans le modèle.

2: Il y a refroidissement des températures au dessus de la couche limite.

3: Il y a augmentation de l'humidité spécifique du modèle dans les bas niveau et en altidude. Il n'y a pratiquement pas de changement dans l'humidité du modèle à 700 hPa. Ceci suggère une

accumulation de vapeur d'eau dans la couche limite, et un transport de vapeur d'eau vers le haut trop fort dans l'atmosphère libre.

4: Les quantités de précipitations et les nuages prévus par le modèle augmentent lors de son intégration, à cause de l'humidification du modèle. Cependant, il y a aussi un problème de "spin up" qui fait que le modèle sous-estime les quantités de précipitations dans les premières 6 à 12 heures d'intégration.

5: En bas de 700 hPa, les épaisseurs sont conservées. Les épaisseurs s'affaissent en haut de 700 hPa.

6: Les prévisions de l'écart du point de rosée correspondent bien avec les prévisions de zéro heure vérificatives, sauf près de la surface.

7: Les prévisions du mouvement vertical correspondent bien avec les prévisions de zéro heure vérificatives.

8: Les prévisions de tourbillon absolu correspondent bien avec les prévisions de zéro heure vérificatives, mais les prévisions de l'advection du tourbillon se détériorent rapidement lors de l'intégration du modèle.

9: La conformité interne du modèle CDNEFR est très bonne. Le mouvement vertical a une structure verticale, qui apparaît, en moyenne, physiquement acceptable. Le mouvement vertical correspond généralement à une convergence dans les bas niveaux et à une divergence en altitude.

10: Il existe une bonne relation entre le mouvement vertical et l'advection de tourbillon dans le modèle CDNEFR.

11: Il existe une relation entre le mouvement vertical et le tourbillon dans le modèle CDNEFR. Cette relation est généralement plus faible que celle entre le mouvement vertical et l'advection de tourbillon.

12: Il existe une relation entre le mouvement vertical et le laplacien de l'advection des températures dans le modèle CDNEFR. Cette relation est généralement plus faible que la relation entre le mouvement vertical et le tourbillon, et que celle entre le mouvement vertical et l'advection de tourbillon.

13: L'advection du tourbillon et le laplacien de l'advection de température contribuent en partie au mouvement vertical et créent une modulation sur le mouvement vertical.

14: Il y a une bonne relation entre le mouvement vertical et l'advection du tourbillon à 500 hPa par le vent thermique dans le modèle CDNEFR, surtout pour le mouvement vertical aux niveaux au-dessus de 850 hPa.

15: La relation entre le mouvement vertical et les quantités de précipitations prévues et le taux instantané de précipitations est très bonne dans le modèle CDNEFR.

16: Les quantités de précipitations prévues par le modèle corrèlent très bien avec les observations de quantités de précipitations.

17: Le taux instantané de précipitations prévu par le modèle CDNEFR corrèle très bien avec les observations de quantités de précipitations.

18: Le mouvement vertical, surtout à 700 kPa, apparaît comme un outil intéressant pour prévoir les quantités de précipitations. C'est, en fait, le deuxième meilleur choix comme prédicteur, après les quantités de précipitations prévues (ou le taux instantané de précipitations).

19: Il existe une certaine relation entre l'humidité relative prévue et les observations de quantités de précipitations, surtout aux niveaux de 850 et 700 hPa.

20: L'advection de tourbillon, tant par le vent réel que par le vent thermique est pratiquement inutilisable comme outil prévisionnel, quant à la prévisions des quantités de précipitatons.

4.0 CONCLUSIONS.

Les résultats présentés ici sont très stables, la période couverte étant suffisamment longue et la quantité de données utilisées étant suffisamment grande. Les données utilisées ont été extraites à la résolution du modèle, minimisant les interpollations spaciales, qui introduisent un lissage sur les champs. Ceci est un avantage sur l'étude statistique publiée précédemment (Verret, 1988).

Il s'avère que les résultats présentés à la section 3.0, compilés sur les deux cycles de production 00 et 12 TU ensemble, s'appliquent tout aussi bien aux intégrations faites à 00 TU et à 12 TU séparément. Très peu de différences entre le comportement du modèle CDNEFR pendant les mois d'hiver et son comportement pendant les mois d'été, ont pu être décelées pendant la période couverte par la présente étude.

Le glissement de la climatologie du modèle, soit une chûte des hauteurs, un refroidissement et une augmentation de l'humidité spécifique, constitue une caractéristique des intégrations du modèle CDNEFR. Cependant cette caractéristique se retrouve dans de nombreux autres modèles numériques, dont entre autres, le modèle spectral canadien (Daley et al, 1979) et la version du modèle CDNEFR à 152.4 km de résolution, comme l'étude de Verret (1988) l'a démontré.

La structure verticale de l'atmosphère simulée par le modèle CDNEFR est physiquement acceptable. Particulièrement, la structure verticale du mouvement vertical, qui a été étudiée plus en détails ici, apparaît, en moyenne, comme physiquement correcte.

Finalement, un des points majeurs qui ressort de la présente étude, est le fait que le mouvement vertical prévu par le modèle CDNEFR, apparaît comme un bon outil prévisionnel. Le mouvement vertical ressort comme étant un meilleur guide de prévision que les advections du tourbillon.

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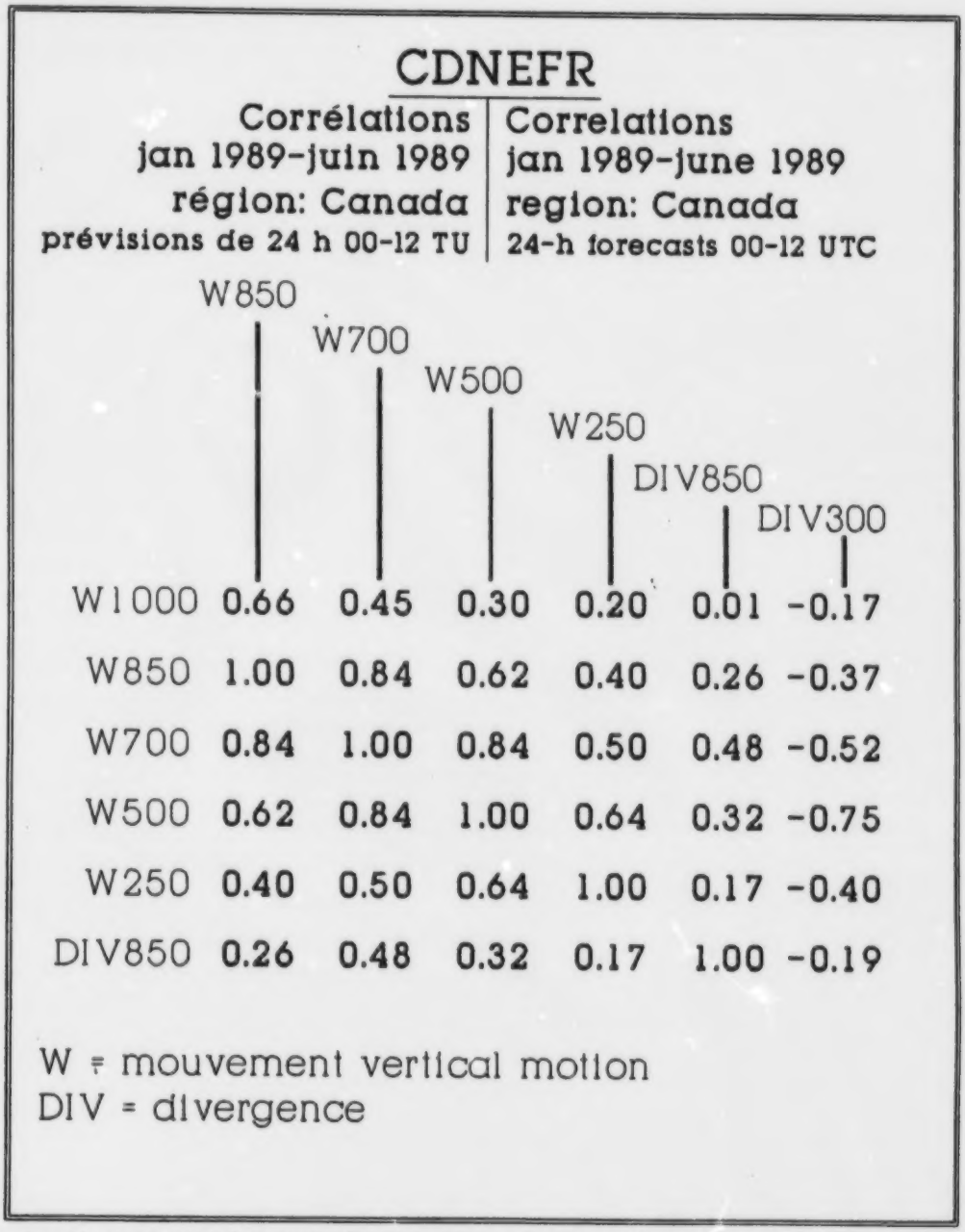

Figure 2: Corrélations croisées entre le mouvement vertical à 1000, 850, 700, 500 et 250 hPa et la divergence à 850 et 300 hPa.
Le mouvement vertical ascendant est négatif. Les corrélations croisées sont calculées pour les prévisions de 24 heures du modèle CDNEFR.

SEASONAL AND GEOGRAPHICAL VARIATIONS IN PREDICTING PRECIPITATION BY TWO OF NMC'S OPERATIONAL BAROCLINIC MODELS

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Abstract

This paper assesses the performance of the NMC Nested Grid Model during a one-year period (March 1988-August 1989) and the NMC spectral model during two 68-day periods, one spring and one summer. Seasonal and geographical variations of precipitation bias and threat scores are discussed for each model. Differences in model performance in predicting various amounts of precipitation are described.

INTRODUCTION

Forecasting of precipitation amounts and probabilities has become increasingly dependent on model and model-derived guidance. To use the various kinds of model output most efficiently, meteorologists need to know the characteristics and systematic deficiencies of the operational models in predicting precipitation. Several studies have been conducted to meet this need, such as those by Jensenius (1988, 1989), Junker et al. (1989), and Junker and Hoke (1989). Except for the latter, none of these studies has attempted to link model performance in predicting precipitation to geographical location.

This paper assesses the performance of NMC's Nested Grid Model (NGM) and spectral model (AVN/MRF) in predicting precipitation at selected stations distributed across the United States and extreme southern Canada. Specifically, this study was undertaken for several reasons:

1) to determine the variability of model precipitation as a function of month, season, and geographical location;

2) to determine the extent to which model performance differed for various precipitation thresholds; and

3) to provide insight into possible causes of model precipitation forecast errors.

METHOD

Two different sets of data were used to assess the models. A 59-station network distributed across the conterminous U.S. was used to verify NGM 12-24-h precipitation forecasts of 0.01 in. or greater (measurable precipitation). The total number of times that threshold of precipitation was predicted, observed, and correctly predicted was tabulated for each station for April 1988 through August 1989. Monthly bias and threat scores were then calculated at each station and these values were plotted by location.

In this paper, bias (B) and threat score (T) for a given amount of precipitation are defined as

$$B = F/O \times 100\%,$$
$$T = (H/(F+O-H)) \times 100\%,$$

where F is the number of times the threshold of precipitation was forecast, O is the number of times the threshold of precipitation was observed, and H is the number of times the threshold was forecast correctly. Bias indicates how well the model predicts the number of times rainfall occurred at a station, but not whether the model correctly predicted the period in which the rain occurred. A perfect bias is one. A bias over one indicates a threshold is being predicted too often, a bias under one that the threshold is being underpredicted. Threat score gives a measure of how accurately a threshold is being predicted. The score varies from zero to one, with unity being the perfect score.

A similar procedure was followed during two separate 68-day periods (one in spring and the other in summer) to verify 24-48-h NMC spectral model precipitation forecasts valid at 0000 UTC. The precipitation amounts studied were 0.01 in. or more and 0.50 in. or more using 150 stations distributed across the U.S. and southern Canada. To assess the 0.50 in. or more threshold, the two 68-day periods were combined to ensure a large enough sample for statistical significance.

RESULTS

The performance of the NGM varied significantly during the year. Fig. 1 shows the bias (top number) and threat score (bottom number) for measurable precipitation for the NGM during April 1988. Note the area with a bias over 2 was confined to the Rio Grande Valley and southern Oregon. The area having a high bias increased dramatically during May (not shown) and by summer covered much of the eastern two thirds of the country. The extensive area where the NGM overpredicted the frequency of 0.01 in. remained relatively unchanged through September 1988 (not shown) before starting to shrink during October (not shown). During the winter of 1988-1989 (Fig. 3) the area with a bias exceeding 2 was generally restricted to southern Texas, the extreme Southeast, and the Rocky Mountain region. In general, threat scores were highest in winter and lowest in summer and were lowest in the Intermountain Region as well as in areas where the bias exceeded 2.

The performance during June 1988, however, was much different than during June 1989 (not shown). The NGM performed much better during the latter--with less overprediction and with higher threat scores. June 1988 was extremely dry across the United States, whereas June 1989 was very wet. This difference in model performance indicates that a model cannot be accurately assessed based on one single month or season and illustrates how synoptic regimes can play an important role in how a model behaves.

As mentioned earlier, the area where the NGM overpredicted the frequency of rainfall contracted during the fall and was restricted to the South during winter, then increased in spring and early summer. This seasonal variation of the precipitation bias appears to be related to temperature and its effect on surface evaporation. Several tests have shown that varying the soil wetness has a marked effect on the model's performance in predicting precipitation. With one alternate scheme (the Penman-Monteith method), surface evaporation was reduced to the extent that threat scores were reduced. Another test, in which the soil wetness was simply reduced by 20%, decreased the overprediction of summertime precipitation (21-31 July 1989) by 25% without degrading threat scores.

The spectral model behaved in a manner similar to the NGM in several ways. The bias for measurable precipitation was generally higher in summer (Fig. 4) than spring (Fig. 5), while the threat score was usually lower in summer than spring. Like the NGM the AVN/MRF overpredicted the frequency of measurable precipitation more often over the South during summer than elsewhere. Fig. 4 illustrates this point showing a bias exceeding 2 over much of the Southeast during a 68-day period ending 25 September 1989. Pockets with a bias over 2 were also located over a portion of the Rocky Mountain region and over southern Texas. The model was also similar to the NGM in showing a low bias over the Intermountain Region but was different in maintaining a low bias across the entire West whereas the NGM (Fig. 2) usually maintained a high bias along the Pacific Northwest coast.

A change to the parameterization of evaporation over land in the AVN/MRF in May 1988 reduced the overprediction of lighter precipitation (not shown) in the medium range. The change also appeared to affect the bias for heavier amounts during 24-48-h forecasts. In Fig. 6 asterisks show the bias for 0.50 in. or greater for a period during January 1988-August 1989. The change to the soil wetness was implemented in May 1988. It apparently helped reduce the high bias (overprediction) the following winter. The black squares in Fig. 6 represent the bias during June, July, and August 1987 prior to the change and suggest the change may have contributed to the underprediction of heavier amounts during summer.

Though the AVN/MRF generally underpredicted heavier rainfall during the convective season, the model's performance varied significantly by geographic locations. Fig. 7 shows the average bias and threat score for different areas across the United States and southern Canada. The AVN/MRF strongly underpredicted the frequency of 0.50 in. or more of precipitation across the South, an area where it overpredicted the occurrence of light precipitation. (Tests on the NGM suggest this apparent paradox may be partly due to the stabilizing effect of the Kuo parameterization in the AVN/MRF.)

Fig. 7 shows that the AVN/MRF underpredicted the occurrence of heavier precipitation over the Ohio Valley and eastern Great Lakes region, while overpredicting over the western portions of the Great Lakes area as well as along and just east of the Appalachian and Rocky Mountains. The maximum in bias over the southern Appalachians and southern Rockies corresponds closely to maxima in the climatological soil wetness used in the AVN/MRF at that time during August 1988 and is consistent with the observation by NMC forecasters that the frequency of upslope precipitation was overpredicted during the summer of 1989.

CONCLUSION

This study illustrates that model performance in predicting precipitation varies depending on season, geographic location, and precipitation amount (threshold). Results also show that soil wetness affects model performance and is partially responsible for the NGM's overprediction of precipitation during summer. Tests reducing soil wetness over land were found to reduce the overprediction of precipitation by the NGM.

Threat scores were generally worse during the summer. Both models overpredicted the occurrence of light precipitation during summer, especially in the South. As expected, threat scores were poorer in regions where the bias differed significantly from 1. Threat scores were lowest over the West and the South during summer and were highest in the North and East during winter. It should be noted that in December 1989 a more realistic scheme was implemented to determine initial soil wetness in the AVN/MRF. This change may have altered the spectral model performance in predicting precipitation from what has been shown in this study.

Work is underway at NMC to improve the performance of precipitation forecasts. A new regional model (the eta model) is being developed that has improved bias and threat scores over those of the NGM, especially for the heavier amounts (Black and Mesinger, 1989). Plans for the spectral model include increasing the resolution from approximately 160 km to 110 km and from 18 to about 25 vertical layers by the end of 1990, testing alternate convective schemes, use of a vegetation index for soil wetness, and the addition of liquid and cloud-water equations.

ACKNOWLEDGMENTS

The authors are indebted to Dr. Louis Uccellini for his helpful suggestions and support throughout this study.

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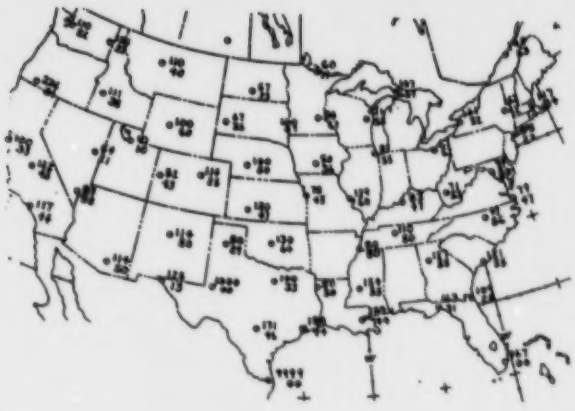

Fig. 1. Plot of the average bias (top number) and threat score (bottom number) of the 12-24-h NGM forecasts of .01 in. or greater during April 1988. Station locations are indicated by small circles.

Fig. 2. Same as Fig. 1 except for June-August 1988.

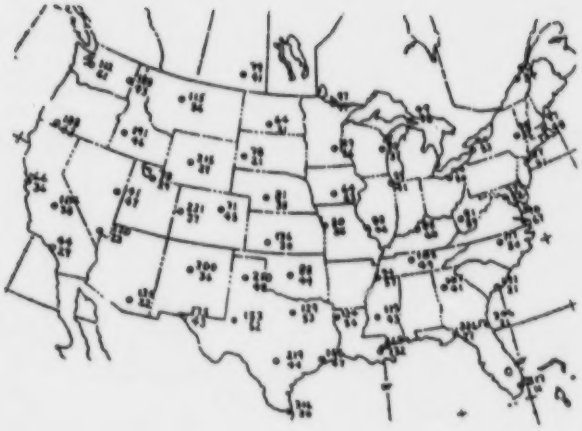

Fig. 3. Same as Fig. 1 except for December 1988-February 1989.

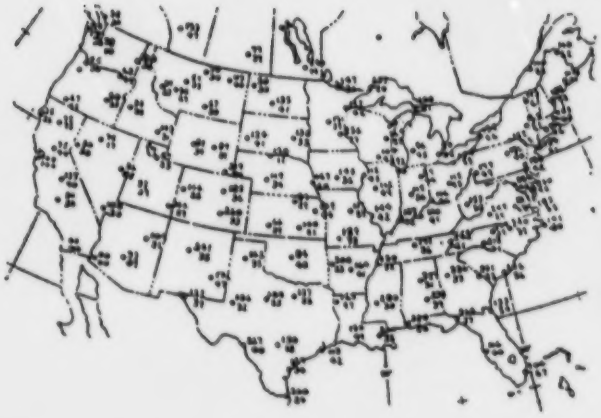

Fig. 4. Same as Fig. 1 except for the 24-48-h AVN/MRF forecasts during a 68-day period ending 25 September 1989.

Fig. 5. Same as Fig. 4 except that the period ends 22 June 1989.

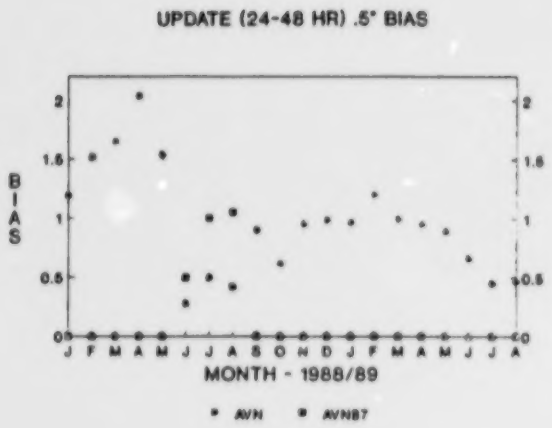

Fig. 6. Asterisks show the monthly bias for 24-48-h AVN/MRF forecasts of 0.50 in. or greater valid at 1200 UTC for January 1988-August 1989. The small black squares show the bias during June, July, and August 1987. Verification is a 31.5-km resolution analysis of precipitation observations from an extensive network over the United States east of 107°W.

Fig. 7. The average bias (B) and threat score (T) for AVN/MRF 24-48-h predictions of 0.50 in. or greater for eight different areas, valid 0000 UTC. Stations used in each area are indicated by small circles.

OPERATIONAL USE OF TRACKING MODEL FORECASTS OF SURFACE SYSTEMS

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ABSTRACT

A database which contains the forecast tracks of cyclones and anticyclones from successive forecast cycles has been created. An evalutation of these tracks over the past year indicates that the confidence in the forecast generally increases as the forecast tracks begin to converge toward a similar solution. If forecast tracks are divergent the confidence level in the forecasts is generally low. Systems that are initialized in the analysis region are simulated better than systems which are forecast to form later in the cycle. Furthermore, systems analyzed on the grid-C are better forecast than systems which move onto grid-C from grid-B during the forecast cycle.

INTRODUCTION

In November of 1988 the National Meteorological Center (NMC) began tracking forecasts of surface cyclones and anticyclones in the operational Nested Grid Model (NGM). This database has proved useful as both a research and operational forecast tool. The research aspects of the database have isolated systematic NGM errors related to forecasting the central pressure, thickness and position of cyclones (Grumm and Siebers, 1989a) and anticyclones (Grumm and Siebers,1989b). The NGM tends to overdevelop cyclones over most of North America and underdevelop cyclones over the oceans. Cyclones are systematically forecast too far west of the verifying position. The NGM tends to overdevelop anticyclones over the oceans and underdevelop anticyclones over North America and it tends to place the anticyclones too far south and east of the verifying position.

In this study two representative cases are examined to show how the NGM forecasts converge toward a solution. These two cases demonstrate the importance of both initial location of the analyzed system and the potential operational utility of this type of dataset.

METHOD

The tracks in this study were collected as outlined by Grumm and Siebers (1989a). In this paper, the actual tracks of systems are taken from the NGM initialized analysis and represent the path of the system in the model's atmosphere. The forecast tracks are not paths of the system but rather

the position for a specific forecast length. For example, in fig. 1b, the track represents the position of each 12 h forecast system #63. The system number and the forecast date and time are printed to the right of each 12 h forecast. In the composite tracks (Fig. 2a & 2b) each track is composed of the initial position and each subsequent forecast position of that system for each forecast cycle, the times are omitted for clarity.

RESULTS

a. Case of a Rapidly Developing Cyclone

Figure 1 shows the track and forecast tracks for system #141 from January 1989. The track (fig. 1a) is the systems path as analyzed in the NGM initialized analysis. This system developed off the east coast of the United States and was first initialized in the NGM on 4 January 1989 at 36.6N and 74.9W with a central pressure of 999 mb. The Regional Analysis and Forecast System (RAFS) initialized analysis positions, used for forecast verification, are shown in Table 1. The system moved rapidly northeastward with rapid cyclogenesis occurring for the first 24 hours as the system tracked over the western Atlantic. By 00Z on 5 January the RAFS initialized analysis located the system at 40.0N and 58.3W with a central pressure of 947 mb. The initial analysis was approximately 9 mb too high as compared to the NMC manual analysis of the system.

The NGM 12 and 24 h forecast tracks for this system are shown in figs. 1b & 1c respectively. Both the 12 and 24 h forecasts initially had some difficulty with the location of initial cyclone development, placing the surface system too far west, in Virginia to the lee of the model terrain maxima. The model 12 and 24 h runs were internally consistent as seen by the convergence of the successive forecast tracks. The corresponding displacement errors (as noted by the closely approximated tracks in the figures) were quite small for all forecasts suggesting that a strong, well initialized cyclone whose track is consistent with successive model runs may be an signal of a good forecast.

The 36 and 48 h forecasts are shown Fig. 1d. Both 36 and 48 h forecasts correctly placed initial cyclone development off the Virginia coast rather than over the United States. Successive 36 and 48 h forecasts continually placed the forecast position near the verifying track. Similar to the 12 and 24 h forecast tracks, the convergent 36 and 48 h forecast tracks also suggested that the NGM was well initialized and was able to repeatedly simulate the development and track of this system.

The highly convergent composite tracks for all forecasts for this system are shown in Fig. 2a. Comparing this figure

with the NGM initialized analysis track in fig. 1a suggests that highly convergent forecast tracks may be a useful indicator of both an accurately initialized and a well forecast system. It is interesting to note that this fast moving, rapidly developing cyclone was particularly well forecast by the NGM.

b. Case of Hurricane Hugo Forecasts

Figure 3 shows the path and forecasts for Hurricane Hugo, which struck Puerto Rico, the US Virgin Islands and finally made landfall on the North American Continent near Charleston, SC. Hugo was system #63 in the September 1989 dataset. Table 2 list the RAFS initialized analysis data of Hugo. Hugo first appeared as a closed surface system on 19 September, 1989 at 21.5N and 68.3W with a central pressure of 1000 mb. Hugo moved slowly WNW for 3 days before recurving.

Unlike the ERICA case, early NGM forecasts of Hugo were very inconsistent as shown in Fig. 2b and Fig. 3d. The initial 36 and 48 hour forecasts had Hugo tracking northward. In the following forecast cycles the NGM began to rapidly accelerate Hugo in a more westward direction. Not until the system was well initialized (a closed circulation in the analysis) did the 36 and 48 h forecasts begin to converge on the track of Hugo.

Figure 3b & 3c show the 12 and 24 forecast tracks of Hugo. For clarity, the actual track of Hugo in the NGM initialized analysis is shown in Fig. 2a and in each subsequent panel. The 12 and 24 h forecasts rapidly converged on a consistent track for Hugo. The 12 h (fig. 3a) forecasts did a remarkable job forecasting the actual track of Hugo through most of its life cycle. The 24 h forecasts initially tracked Hugo south of the verifying track. As Hugo entered the NGM grid-c the forecasts became more consistent. After landfall the 24 h forecasts tended to track the system slightly east of its analyzed track.

DISCUSION/CONCLUSIONS

The two cases presented in this paper and other cases examined over the past year indicate that the divergence or convergence of the forecast tracks of cyclones and anticyclones may be used as a confidence factor in operational forecasts. The result presented here (fig. 2a & 2b) indicate that highly convergent forecast tracks may be a signal to the forecaster that the model is well initialized and able to repeatedly simulate the development of the system. The results from Hurricane Hugo's (fig. 2b & 3d) track indicate that highly divergent tracks may be a signal that the model is having difficulty initializing the

developing system and is therefore unable to consistently forecast its development. However, once the system is well initialized and the forecasts begin to converge on a solution the forecasters confidence in the forecast should increase despite poor initial forecasts.

The tracks of Hurricane Hugo demonstrate that the NGM can make a credible forecast of a tropical system once it is well initialized. Early NGM forecasts of Hugo, when it was out over Grid-b and in a data sparse area emphasize the impact of both poor initialization and the effect of a coarse grid on model forecasts. Once Hugo approached Grid-c and was better initialized the model forecast became very consistent and the NGM did a credible job forecasting both the track and speed of Hugo. The NGM consistently had the Hugo making landfall in SC two days before it struck Charleston, SC.

The results of this preliminary study suggest that an examination should be made to compare how the NGM forecasts strong verses weak systems. It appears that strong systems are typically better forecast than weaker systems. It may also be useful to examine systematic errors in systems which appear in the initial analysis and the successive forecast against the forecasts of systems which form during a forecast cycle. The results presented here suggest that the larger displacement and pressure errors will probably occur in systems which do not initially appear in the analysis.

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TRAK	BLK	DAY	TIME	FCST	LAT	LON	PRESS	THK	T850
63	7	89262	12	0	21.49	68.25	1000.00	5830.00	296.15
63	8	89263	00	0	23.64	69.97	1004.00	5790.00	290.15
63	9	89263	12	0	25.02	71.75	999.00	5810.00	295.15
63	10	89264	00	0	27.05	73.31	996.00	5860.00	300.15
63	11	89264	12	0	28.74	75.73	999.00	5820.00	297.15
63	12	89265	00	0	31.37	78.70	998.00	5800.00	293.15
63	13	89265	12	0	35.50	82.06	999.00	5770.00	290.15
63	14	89266	00	0	41.62	80.10	993.00	5760.00	291.15
63	15	89266	12	0	50.23	70.16	982.00	5680.00	287.15

Table. 2. As in Table. 1 except for system number 63, Hurricane Hugo.

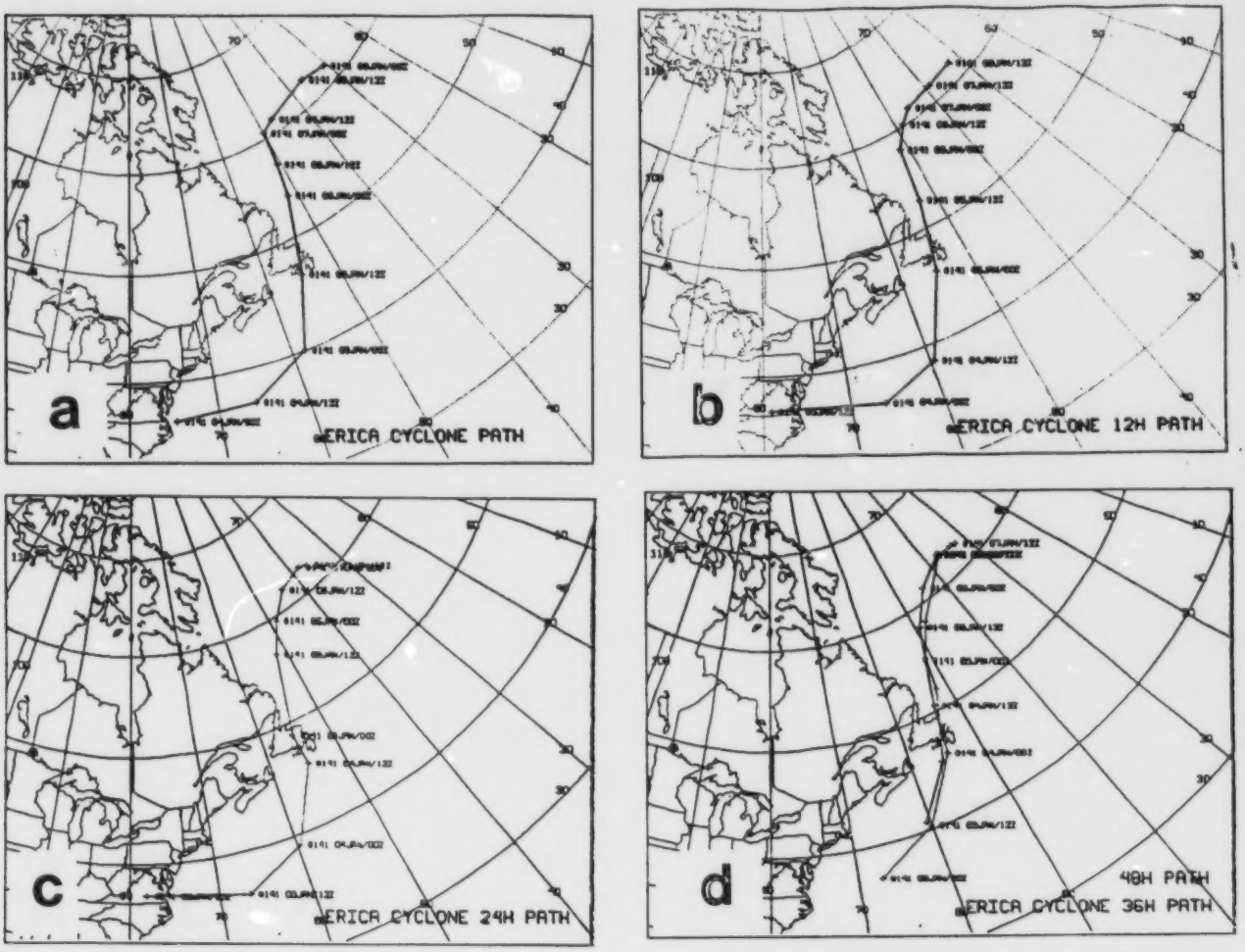

Fig. 1. Tracks of ERICA cyclone during January 1989 for (a) NGM initialized analysis, (b) NGM 12h forecasts, (c) NGM 24h forecasts and (d) NGM 36 and 48 h forecasts.

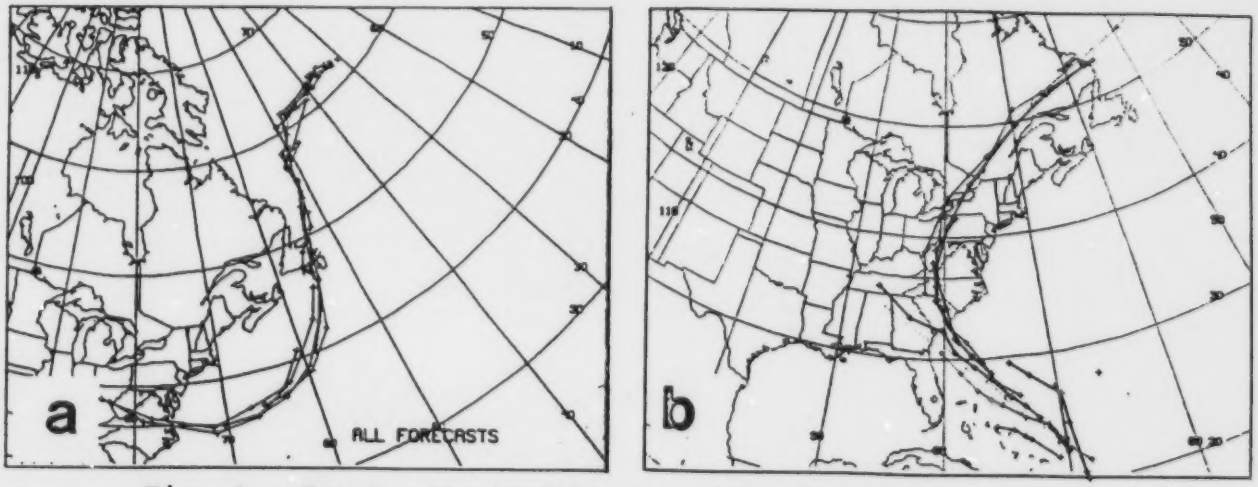

Fig. 2. Tracks of all NGM initialized analysis and forecasts for (a) the ERICA cyclone during January 1989 and (b) all NGM initialized analysis and forecasts for the Hurricane Hugo during September 1989.

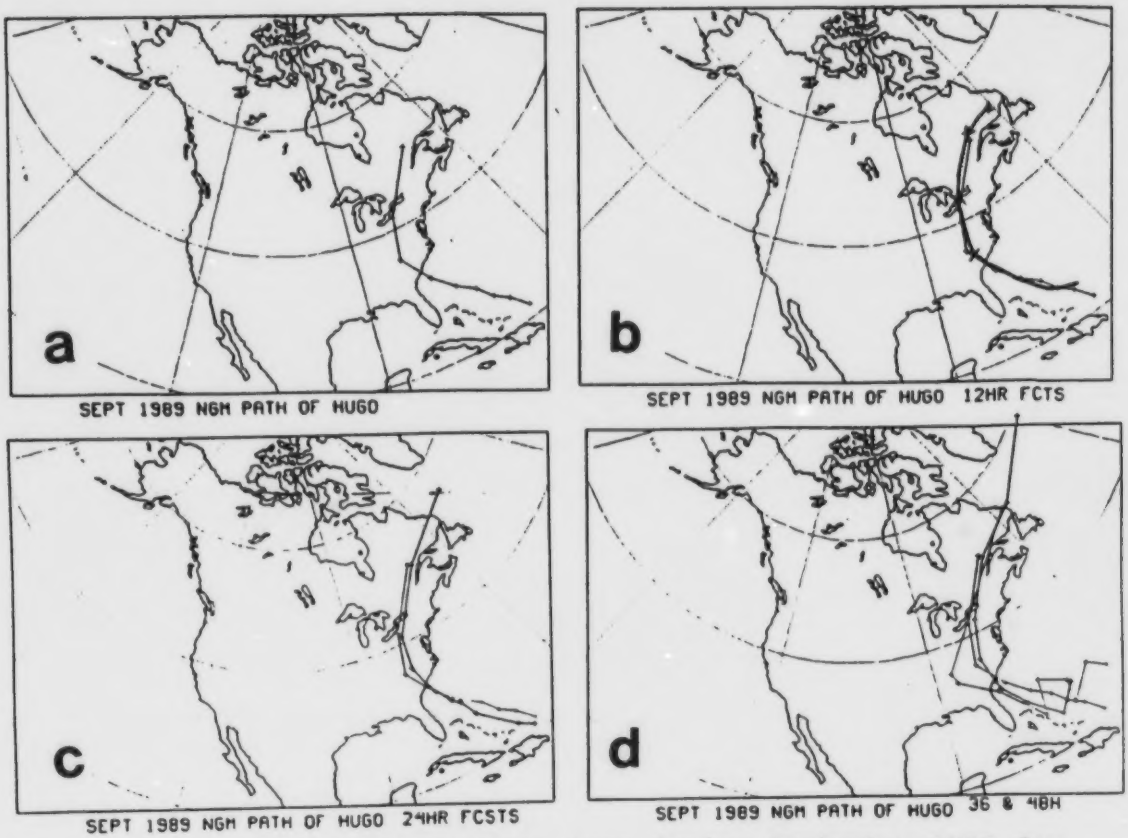

Fig. 3. Tracks of Hurricane Hugo during September 1989 for (a) NGM initialized analysis, (b) NGM 12h forecasts, (c) NGM 24h forecasts and (d) NGM 36 and 48 h forecasts.

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TRAK	BLK	DAY	TIME	FCST	LAT	LON	PRESS	THK	T850
141	3	89004	00	0	36.63	74.95	999.00	5470.00	280.15
141	4	89004	12	0	37.02	65.69	960.00	5600.00	292.15
141	5	89005	00	0	40.00	58.36	947.00	5550.00	289.15
141	6	89005	12	0	46.73	54.94	950.00	5440.00	278.15
141	7	89006	00	0	54.14	51.41	956.00	5430.00	280.15
141	8	89006	12	0	57.24	50.74	963.39	5387.00	282.96
141	9	89007	00	0	60.64	50.28	975.00	5260.00	273.15
141	10	89007	12	0	61.33	46.97	981.00	5250.00	269.15
141	11	89008	12	0	62.75	36.48	988.00	5190.00	266.15
141	12	89009	00	0	61.82	30.81	985.00	5200.00	270.15

Table. 1. Positions of system number 141 from the NGM initialized analysis used for verifying forecasts. Columns include the system number (trak), the data block (BLK), the Julian date (day), model cycle (time), forecast length (FCST), system latitude, longitude, central pressure,

FRACTURED FORECASTS OF OCEANIC CYCLONES IN SUCCESSIVE DYNAMICAL PREDICTION RUNS

By

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ABSTRACT

Forecasts of central pressure made by successive runs of the MRF model out to 5 days range were studied for 40 surface cyclones in the western Atlantic region from December 1988 through February 1989. The largest changes, or fractures, were deepenings of 31 mb, occurring between forecasts verifying for the same date at 5 and 4 days range. In contrast, the largest change from day 2 to day 1 was 12 mb. The two cases of largest fracture showed different structure. The first grew initially aloft, then abruptly and violently at the surface, while the second developed simultaneously, more strongly at the surface.

RESUME

Des prévisions de pression centrale faites par des intégrations successives du modèle MRF jusqu'à 5 jours ont été étudiées pour quarante dépressions sur l'ouest de l'Atlantique entre décembre 1988 et février 1989. Les plus grandes différences, ou fractures, furent des creusages de 31 mb établis entre des prévisions de 4 et 5 jours valides à la même date. Par opposition, la plus grande différence pour des prévisions de 2 et 1 jour fut de 12 mb. Les 2 cas concernant les plus grandes " fractures" montraient des structures différentes. Dans le premier cas, elle est apparue en altitude puis abruptement et violemment en surface. Dans le second cas, les différences se développèrent simultanément en altitude et en surface mais plus fortement en surface.

I N T R O D U C T I O N

During the ERICA field phase December 1988 through February 1989, surface cyclone behavior was examined in the forecasts out to 5-days range produced from an initial time of 0000 UTC by the Medium-Range Forecast (MRF) run of NMC's global spectral model. We considered all cyclones occuring on two or more consecutive days which tracked, or were forecast to track, over the region 35-30 North Latitude and from 50 West Longitude to the North American coast. In the initial analyses, 40 such cyclones were found. These systems were traced back as far as 90 West Longitude and forward as far as the northeastern North Atlantic in some cases. The tracks of these storms across the ERICA region is shown in Fig.1. In addition, 3 false alarms were

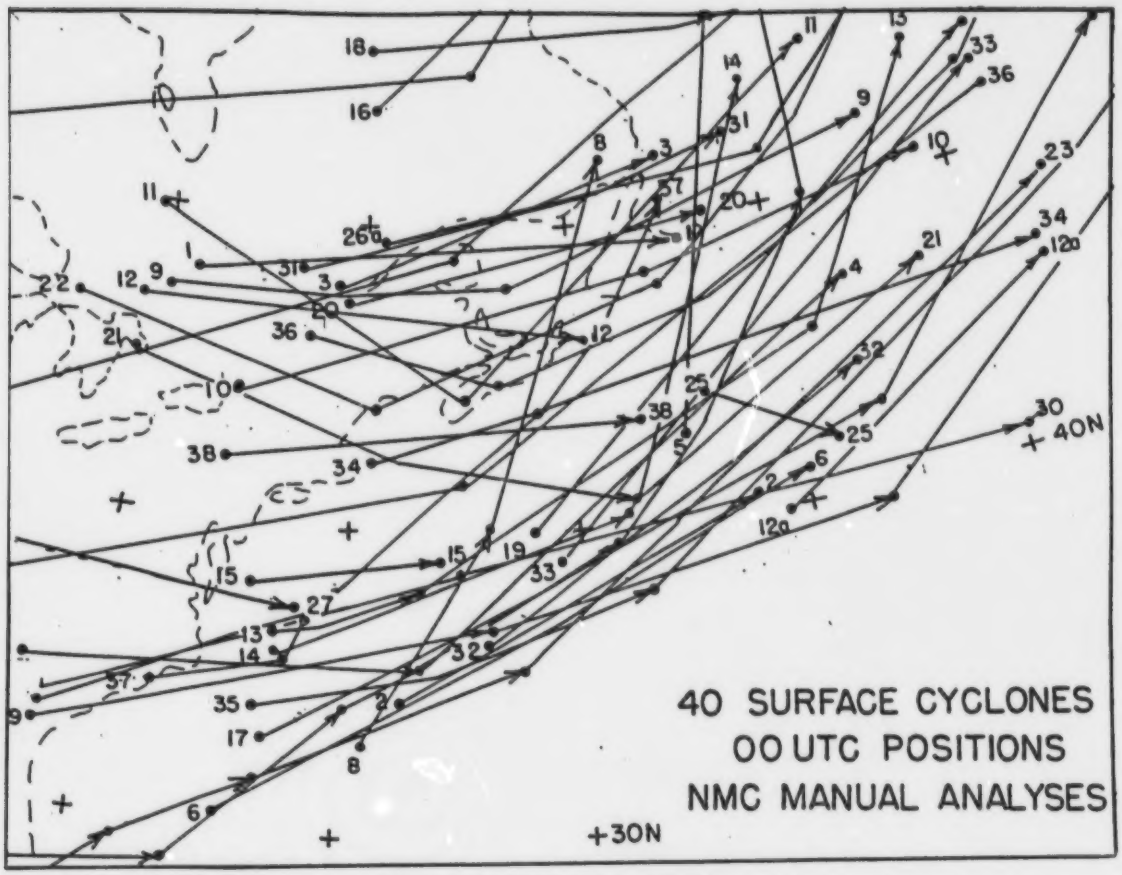

Fig.1. Cyclone tracks through the ERICA region, December 1988 through February 1989, numbered sequentially.

predicted at some range but never materialized in the initial analyses.

METHOD AND RESULTS

Because the focus of ERICA was on explosive deepening, we have first examined instances in which successive forecast runs showed moderate or large changes in the central pressure of a given cyclone. For a given verification time, forecast pairs for ranges of 96 h vs 120 h (days 4-5) down to ranges from 0 h vs 24 h (days 0-1) were examined. Instances were considered in which the change in predicted central pressure one range to the next was at least 4 mb. Of the 106 instances, 42 represented a less-deep center at the shorter range. This result is consistent with the failure of positive bias in predicted central pressure to grow with range in the MRF forecasts. It was about 4 mb from day 0 through day 5.

The changes in predicted central pressure (the analyzed value, for day 0) were stratified into groups of about a dozen instances and percentages were calculated for each pair of successive ranges. Results are given in Table 1. Despite the roughness of the distributions, due to small sample size, it is clear that really large forecast fractures did not occur at short ranges. In fact the two largest changes, 31 mb, occurred between days 4 and 5. The largest change from days 3 to 4 was 27 mb, from days 2 to 3 22 mb, from days 1 to 2 12 mb, and from days 0 to 1 10 mb.

Table 1

Percentage distribution of pairs of ranges of successive forecasts (days) yielding specified changes of cyclone central pressure (mb)

Change	N	0-1	1-2	2-3	3-4	4-5
31-17	12	0	0	17	33	50
16-14	13	0	0	15	46	38
13-12	16	0	6	19	44	31
11-9	13	15	0	23	46	15
8-7	14	7	21	21	36	14
6	10	30	0	40	0	30
5	14	14	7	21	21	36
4	14	7	21	21	21	29

Most of the 40 cyclones showed one or more fractures of at least 10 mb at some point in the forecast runs in which they appeared. Only 2 such fractures were noted in the first two days of the forecast, 9 between the second and third days, and 37 in successive forecasts at longer range. (In 16 instances a low appearing in a forecast run was not present at all in the preceding run, while in 5 cases a later run failed to show a cyclone present earlier.) From this information and that in Table 1, the impression is of exponential growth of difference in forecasts with range, irrespective of which forecast proved to be more accurate. The situation is not quite that simple, however, as we will see.

The two extreme cases of forecast fracture are illustrated below. In both instances the later (updated) forecast was more accurate. The first of these (Cyclone 14 in Fig.1) led to ERICA IOP 4. In the upper portion of Fig.2, the 120-h forecast for 0000 UTC 5 January showed no sign of a cyclone within the region of interest, and in fact it was planned at this point to pursue a storm on 3 January, predicted from an initial time on 31 December to lie well NE of Newfoundland by the 5th.

The forecast initiated 24 h later, however, produced the dramatically different picture for 0000 UTC 5 January shown in the lower portion of Fig.2. An earlier high of 1019 mb S of Nova

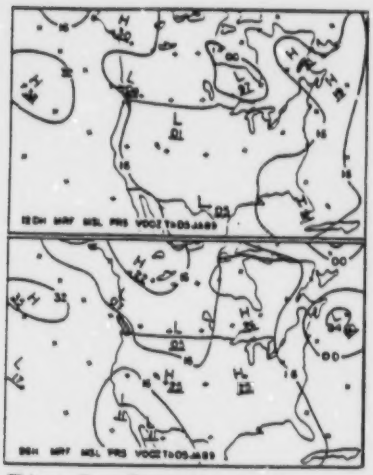

Fig.2. Predicted sea-level isobars at 16-mb interval

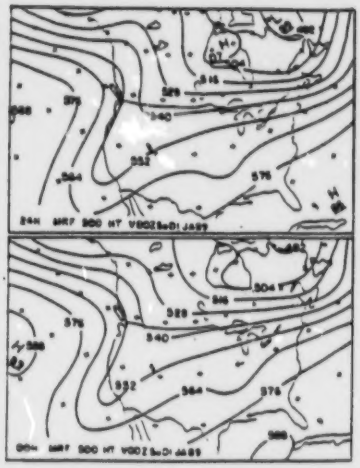

Fig.3.Predicted 500-mb contours at 6-dam interval

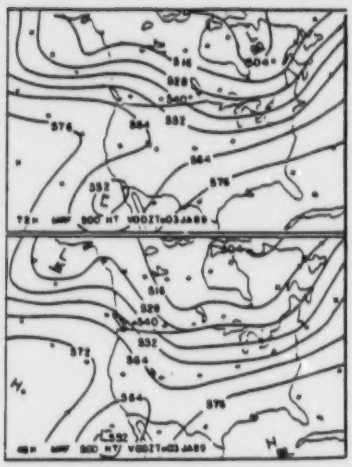

Fig.4. Same as Fig.3

Scotia was replaced by a rapidly deepening low of 980 mb at nearly the same location! At first the thought was to observe both storms, but when this proved logistically impossible, and when the next MRF run, from 2 January, predicted a central pressure of 964 mb on the 5th in this later storm, it was decided to forego the earlier one. A low-level flight grazing the center at around this verification time indicated a minimum extrapolated sea-level pressure of 938, and informal record for an extratropical cyclone so far south.

Explosive cyclogenesis in the western Atlantic region is invariably preceded by the approach of a finite-amplitude upper-level trough from the west. The first thought in explaining the discrepancy, therefore, was that the 24-h 500-mb forecast verifying on 1 January, when the successful updated forecast was initialized, might have been seriously in error. This forecast and the verifying analysis are shown in Fig.3. Contrary to expectation, the patterns looked virtually identical. Close inspection shows the ridge in the Canadian Rockies to be 6 dam weaker in the later forecast, with trough to its west about equally deeper over a small part of the Gulf of Alaska.

This "discrepancy center" grew linearly with time as it moved east, reaching 18 dam by 3 January, when it was manifested in a sharp new trough in the updated forecast (Fig.4, lower portion) in west-central Canada, just emerging from the Rocky Mountains and not seen at all in the earlier forecast (Fig.4, upper panel). At this time the corresponding discrepancy center at sea level was about 8 mb, unchanged from its value 2 days earlier. The growth aloft, therefore, did not extend to the

surface, where there was little indication of a ruckus until 4 January. In this case, the ERICA problem (prediction of explosive surface cyclogenesis) appeared to be not a Western-Atlantic problem, but a Rocky-Mountain problem.

The second case immediately demonstrated a lack of universality in the above scenario. This low (fragmentarily seen as cyclone 16 in Fig.1) was over the continent during much of its deepening, with a last burst as it crossed the Labrador coast and reached the ocean. The development is illustrated, in different format, in Figs.5-7. Only the updated pattern is shown, along with the pattern of change from the earlier forecast verifying at the same time. Sea-level and 500-mb patterns are shown together. At 24-h range (Fig.5) there was little apparent change from the 48-h forecast verifying at 0000 UTC 7 January. Close inspection, however, shows at both levels a discrepancy doublet, the updated forecast showing a slightly deeper low and upper trough and a slightly stronger high and upper ridge. Discrepancies at the two levels were of equal strength. (At 1000 mb, 3 dam of height difference corresponds to about 4 mb of difference in sea-level pressure.) The 500-mb centers lagged the lower-level centers by perhaps 1/8 of a wave length, favoring enhanced baroclinic intensification.

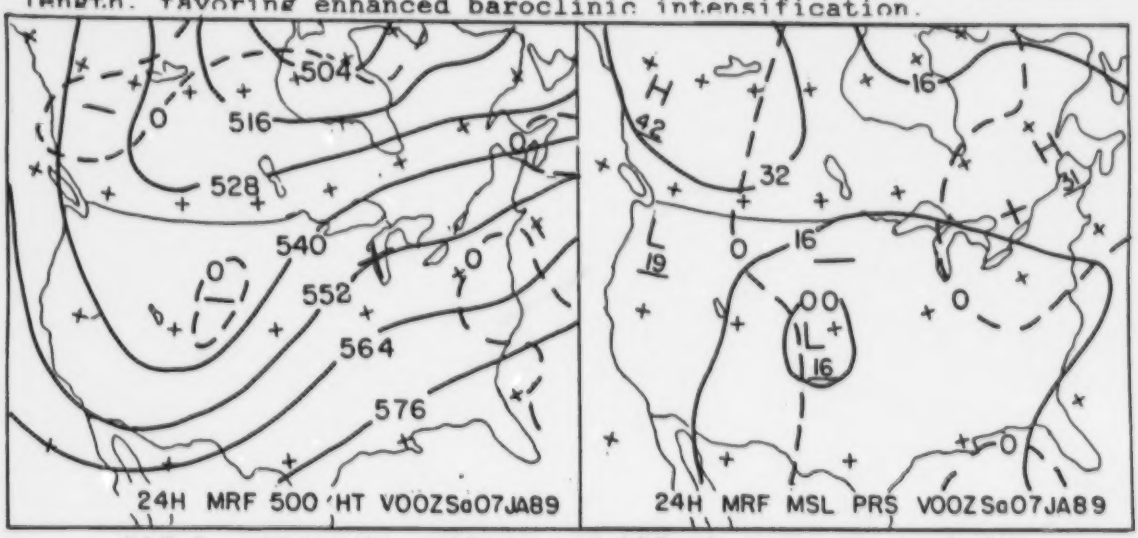

Fig.5. Sea-level isobars and 500-mb contours (solid) and change from preceding forecast (dashed)

By 72 h (Fig.6) the updated forecast showed a large change from the corresponding 96-h forecast. The same doublet was apparent at 500 mb, with substantial growth of discrepancy in the trough. In the sea-level isobars there was an even larger discrepancy centered just NE of a rapidly intensifying center still over land. Contrary to the previous case, the discrepancy grew simultaneously at the two levels, with greater growth at the surface. A SWward lag was still apparent at 500-mb relative to sea level.

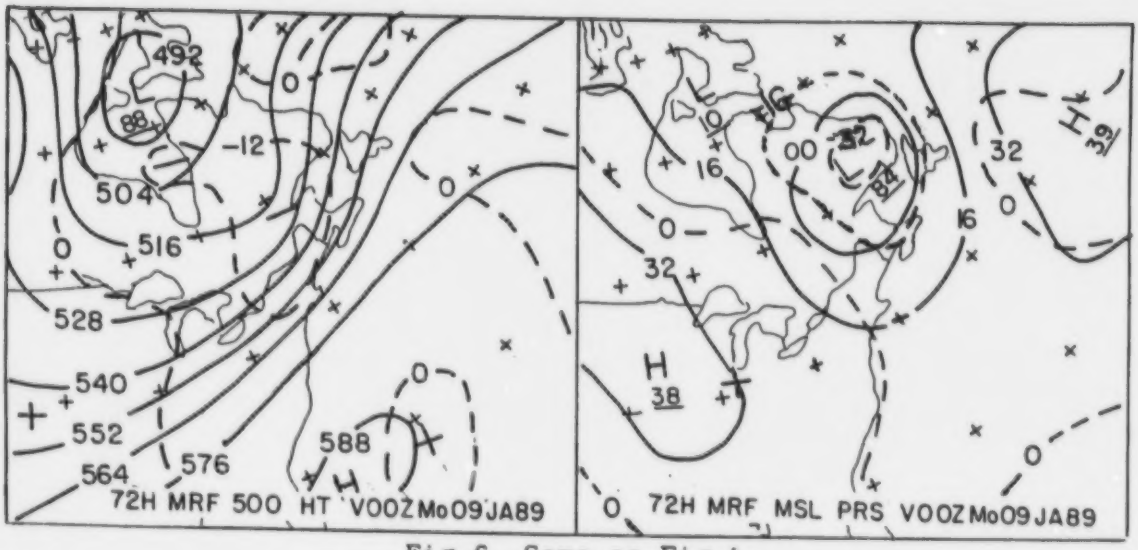

Fig.6. Same as Fig.5

At 96 h (Fig.7) the updated sea-level low was 31 mb deeper than on the earlier forecast, and in fact was 5 mb deeper than the Northern Hemisphere manual analysis for 10 January. At 500 mb the negative discrepancy center had overtaken the sea-level center and matched it in intensity.

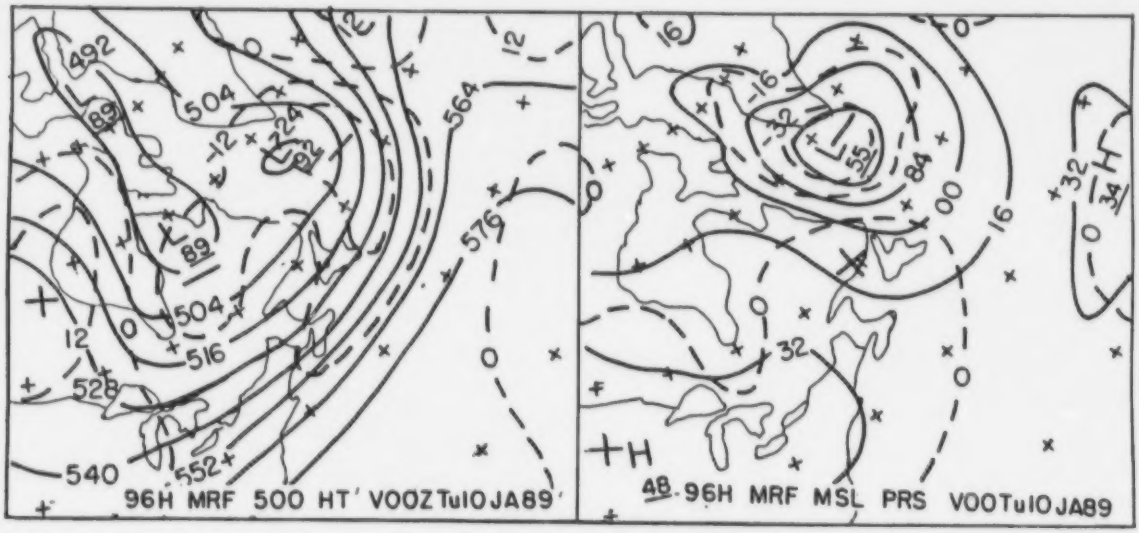

Fig.7. Same as Fig.5

These results are far from exhaustive. They show at least two modes of difference in the behavior of successive MRF model runs.

THE OPERATIONAL RUNS AT CMC

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1. INTRODUCTION: The Canadian Meteorological Centre's (CMC) automated production system ingests voluminous amounts of data, analyses it, makes a forecast of the future state of the atmosphere and disseminates the information to users within and outside A.E.S., through text bulletins, charts for METSIS, RIDS, DIFAX and Analog Fax. The automated production system consists of a series of operational runs which are sequences of computer jobs executed in btach mode on the various mainframe computers. The main runs are Run 0 in which the Regional Finite Element (RFE) model is executed, and RUN2 in which the Spectral model is executed.

2. Structure of the Production System: The production system is comprised of a suite of operational runs. Figure 1 summarizes the current configuration of the CMC operational production system. There are five major upper air runs and four minor surface runs which are all repeated twice daily. The first cycle starts from observational data at or near 0000 UTC and the second cycle from observational data at or near 1200 UTC. The intermediate observational data at 0600 UTC and 1800 UTC are included within each cycle.

Although the content and purpose of each run differ they share a similar set of fundamental processes. They are data extraction, data assimilation, forecasting the future state of the atmosphere (in so far as the upper air runs are concerned) and a host of post-processing activities. These post-processing activities include complex graphical calculations, a variety of forecast products and diagnostics, archiving analyses and forecasts, verification of forecasts, bulletin preparation, etc. In fact, considerable run time is consumed in post-processing activities.

The five major upper air runs are simply known as Run 0, Run 2, Run 3, Run 4, and Run 5 based upon their sequence of execution stemming from historical evolution. Run 1 was dropped many years ago after its function of producing tephigrams was merged into a post-processing task of Run 2. The surface runs are similarly named sequentially as S1, S2, S3 and S4.

It is often more meaningful to refer to the runs by their general purpose or function. In this manner Run 0 represents the Short Range forecast run, Run 2 the Medium Range forecast run, Run 3 the Final Analysis run (main synoptic hours 0000 and 1200 UTC), Run 4 the Early Analysis run (Intermediate synoptic hours) and Run 5 the Final Analysis run (intermediate synoptic hours 0600 and 1800 UTC).

There are basically two types of surface runs for each of the synoptic hours, a regional analysis and a hemispheric analysis of mean sea level pressure and temperature. Runs S1 and S3 represent the regional surface analyses for 0000/1200 UTC and 0600/1800 UTC respectively with symmetrical cut-off times of 45 minutes. Similarly, Runs S2 and S4 are the hemispheric surface analyses of sea level pressure but with a later data cut-off time of close to three hours.

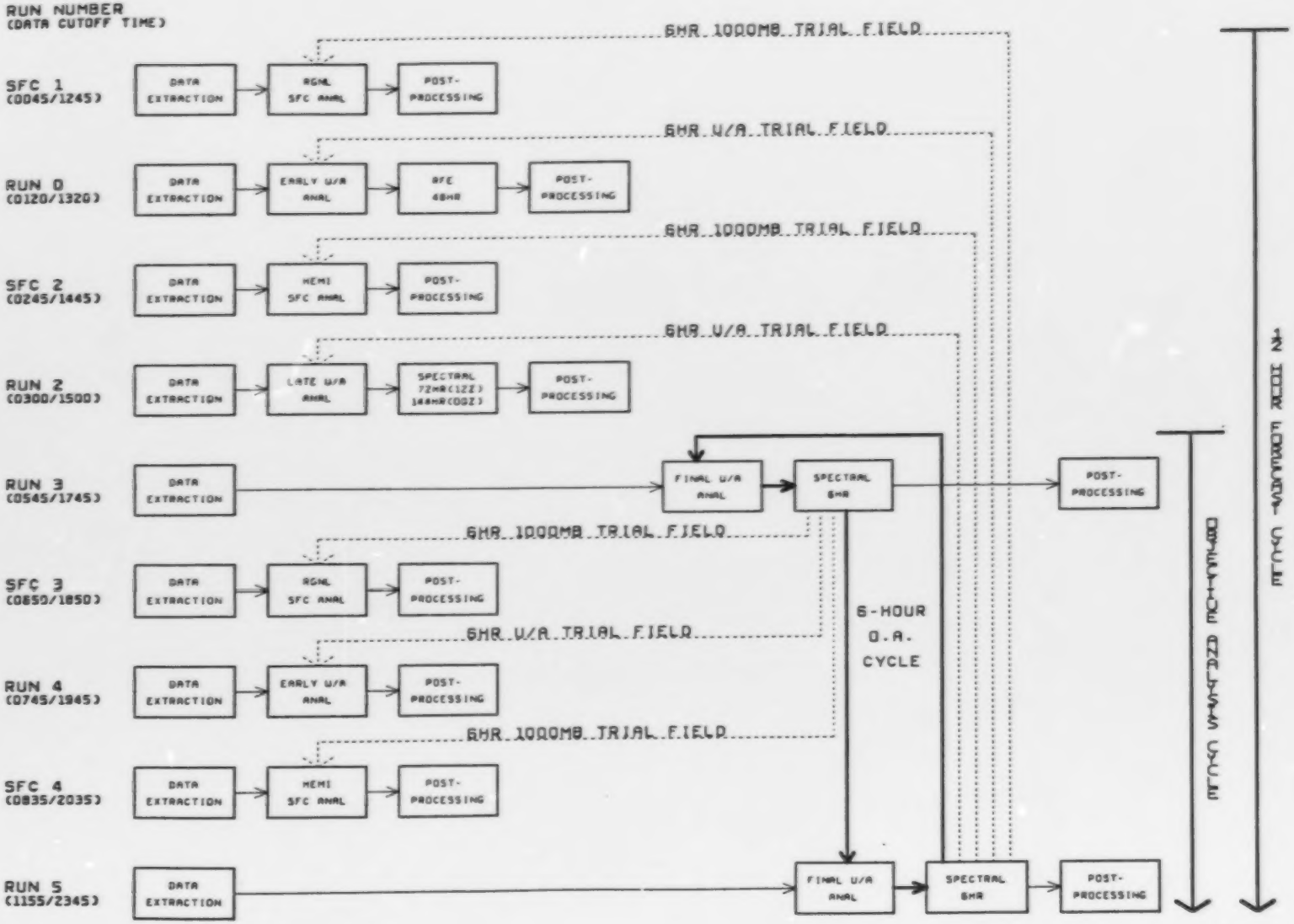
It should be noted that the data cut-off times shown in Figure 1 are approximate since the runs are started manually. The duty meteorologist must decide whether sufficient data has been received to effectively begin the run. On occasions when certain difficulties arise, such as power outages, telecommunication problems or computer hardware problems, decisions on how long to wait and catchup procedures to follow become crucial.

3. Inter-dependencies of the Operational Runs: The heart of the production system is the data assimilation cycle. Figure 1 provides a schematic illustration of the runs and their dependency on the objective analysis cycle. The circuit depicted in solid heavy lines represents the 6-hour objective analysis cycle. The dashed lines represent required input to the various runs. Successful completion of the data assimilation cycle, i.e., Run 3 and Run 5, governs whether the remaining runs can proceed in sequence. As part of the data assimilation cycle a six-hour forecast or trial field is generated for the next analysis period. Run 5 for example will produce a trial field valid for either 0000 or 1200 UTC depending upon which cycle it is completing. Likewise, Run 3 produces a trial field for either 0600 or 1800 UTC. At the start of a new forecast cycle Run 0, Run 2 and Run 3 will require as input the six-hour trial field forecast generated by Run 5 in order to perform the objective analysis at their respective start times. Similarly, Run 4 and Run 5 require as input the six-hour trial field forecast generated by Run 3.

The surface runs also share a similar dependency. The regional surface analyses, i.e., S1 and S3, utilize the six-hour forecast trial fields (1000 hPa reduced to MSL pressure) produced by Run 5 and Run 3 respectively. The hemispheric surface analysis, i.e., runs S2 and S4, also utilize the same six-hour trial field forecast.

RUN DEPENDENCY ON OBJECTIVE ANALYSIS CYCLE

FIGURE 1



AN OPERATIONAL NUMERICAL MODEL TO AID IN FORECASTING SURFACE WINDS IN EASTERN COLORADO

By

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Abstract

A simple fine-mesh numerical model which produces objective forecasts of surface winds is described. Due to its rapid execution time, the model can be used by operational forecasters in real time using computing resources soon to be available in the field.

Résumé

Une description d'un modèle numérique simple à maille fine produisant des prévisions objectives de vents de surface est présentée. Comme le modèle peut être exécuter rapidement, il peut être utilisé en temps réel par les météorologistes d'exploitation en se servant de ressources informatiques bientôt disponibles dans le champ.

I N T R O D U C T I O N

The surface winds along the Front Range of the Colorado Rockies and over the adjacent plains to the east, coupled with the highly varying terrain in this area, play a very prominent role in the local meteorology. Consequently, by increasing the accuracy of wind forecasts for this area, better forecasts of the actual weather conditions can be made.

Climatology, experience, extrapolation and large scale numerical models have been the main methods of producing short term wind forecasts for the aforementioned area. Recently, a numerical model has been developed which produces three hour surface wind forecasts every hour. The novel approach taken in the model's development combines a variety of methods normally reserved for modeling of larger scale atmospheric processes. This keeps the model simple allowing its use in day-to-day forecast operations.

M O D E L D E S C R I P T I O N

The physics are modeled using the one-layer barotropic primitive equations (shallow water equations) written on a tangent plane using standard Cartesian coordinates:

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} + \frac{\partial \Phi}{\partial x} - fv = 0 \qquad (1)$$

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} + \frac{\partial \Phi}{\partial y} + fu = 0 \qquad (2)$$

$$\frac{\partial h}{\partial t} + u\frac{\partial h}{\partial x} + v\frac{\partial h}{\partial y} + h\left[\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}\right] = 0 \qquad (3)$$

where u (v) is the east-west (north-south) wind component, f the constant Coriolis parameter, Φ the geopotential of the free surface of the fluid, and h the depth of the fluid. This model assumes that the fluid is inviscid, homogeneous and in hydrostatic equilibrium.

Equations (1)-(3) are discretized in space using a second order finite difference scheme (Arakawa and Lamb 1981) which retains the conservation laws enjoyed by the differential equations, most notably conservation of total mechanical (kinetic plus potential) energy as well as potential enstrophy (proportional to the square of the absolute vorticity). These conservation properties allow the numerical model to accurately describe the nonlinearity in the equations in the presence of steep topography.

Finite differencing in time is accomplished using a one step, first order predictor-corrector method (Kurihara and Tripoli 1976) which simulates the standard implicit Euler backward scheme. The scheme strongly damps inertial-gravity waves (for stability) while leaving the amplitude of the important meteorological solution relatively unaffected.

The finite difference grid covers a square area roughly 560 km on a side with a gridlength of 10 km. The underlying terrain is a scaled version of the actual terrain present in the domain. The time integration is performed using a timestep of 30 seconds.

Boundary conditions are those described by Perkey and Kreitzberg (1976) and consist of a "sponge zone" around the perimeter of the domain which acts to absorb incident inertial-gravity waves while allowing the lower frequency waves to "pass" out of the domain relatively unimpeded.

Initial u and v surface wind components are obtained from a new high resolution, hourly gridpoint analysis output from the Local Analysis and Prediction System (McGinley 1989). The initial fluid depth is acquired by computing a streamfunction based on the assumption that the winds are in geostrophic balance at the beginning of the integration.

C A S E S T U D Y

Figure 1a shows the initial wind field at 1700 UTC 5 October 1989. Features to note include the anticyclonic circulation near the center of the domain and the brisk winds over the eastern part of the grid. Figures 1b-d show the forecast winds at 1800,

1900, and 2000 UTC 5 October 1989, respectively. Note the generally smooth evolution of the flow throughout the domain. The anticyclone remains intact throughout the integration and another weaker one develops to the south at 1800 UTC then decays by 2000 UTC. The moderate north to northwest flow over the eastern part of the domain remains relatively unchanged during the forecast period. The winds over the western sections of the domain do vary quite a bit during the forecast. This section of the grid contains the steepest topography and it was suspected from the outset that the model would have difficulty in this area.

The verifying analyses (not shown) indicate that the model performed quite well. The main anticyclone did remain intact through 2000 UTC and the weak one to the south did develop and dissipate about as forecast. Winds in the eastern part of the domain remained north or northwesterly but decreased somewhat during the period, more so than forecast.

C O N C L U S I O N S

The physical model described above is admittedly very simple and in fact may not be valid under certain circumstances, especially those in which thermal and/or frictional affects become the dominant forces producing the winds. However, under conditions where the geostophic assumption is more valid the model does produce useful short-range surface wind predictions.

The simplicity of the model makes it attractive in the operational environment due mainly to its rapid execution time. Surface wind forecasts similar to those in Figure 1 can be available 20-30 minutes after the winds have been observed.

It is anticipated that this model will, in the near future, become part of the new technology currently being tested at the National Weather Service Forecast Office in Denver. In this environment, analyzed gridded surface winds and three hour forecasts will be available each hour.

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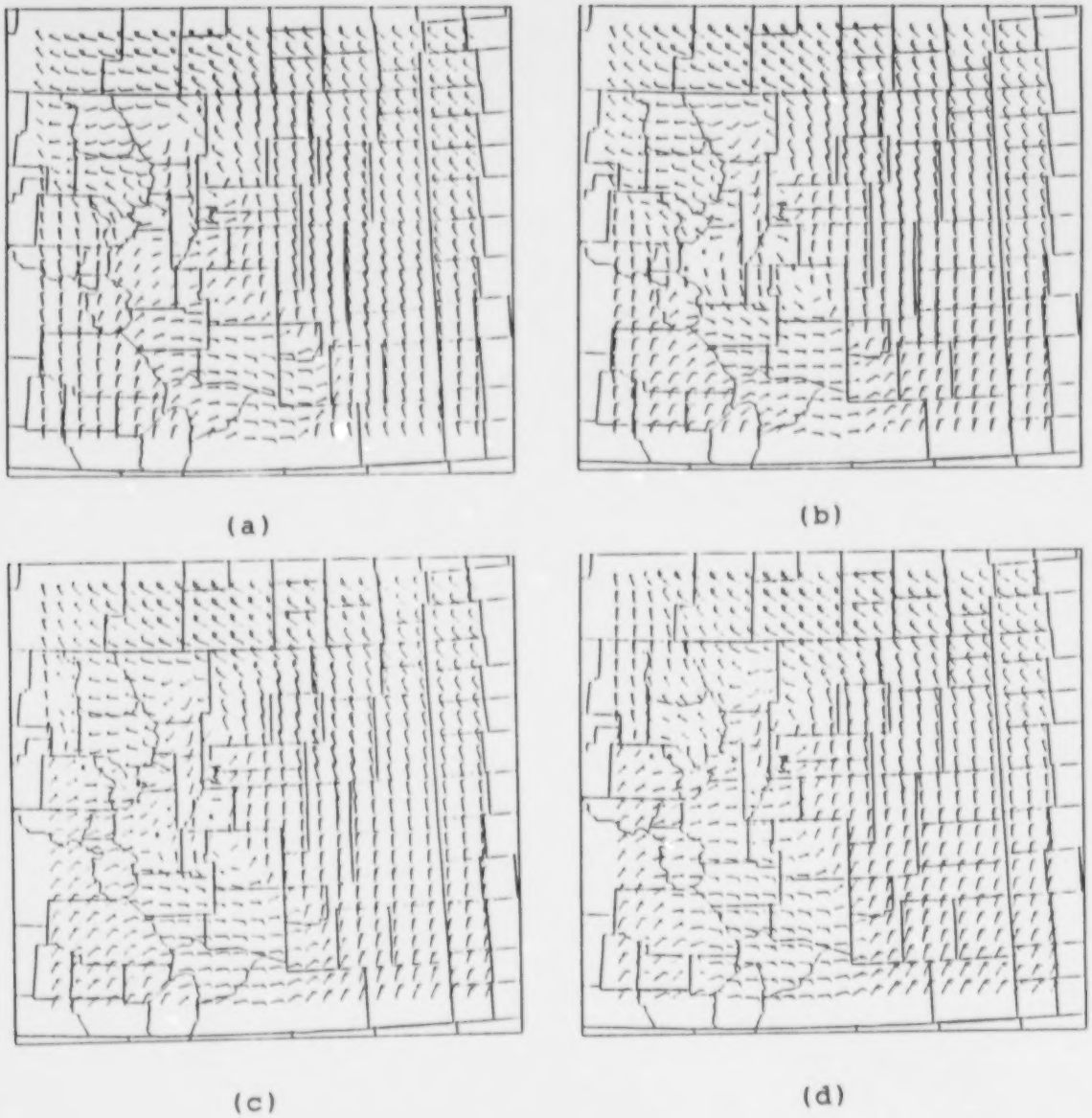

Figure 1. (a) Initial and (b) 1-hour, (c) 2-hour, and (d) 3-hour forecast winds over eastern two thirds of Colorado. Wind speed in knots. See text for details.

VÉRIFICATION DES PRÉVISIONS NUMÉRIQUES DU TEMPS AU CENTRE MÉTÉOROLOGIQUE CANADIEN

Raymond Rioux
Surveillance et contrôle de la qualité

Résumé

Les vérifications faites par le CMC pour ses usagers se réfèrent aux régions telles que définies dans "La revue mensuelle" et utilisent l'indice S1, le biais, l'écart quadratique moyen et l'anomalie climatologique. Celles faites dans le cadre du projet de l'OMM couvrent les régions décrites ci-dessous et utilisent les indices S1 (appelé "Skill Score" par l'OMM), le biais, l'erreur quadratique moyenne et la corrélation. Ces statistiques sont calculées sur les champs de la pression au niveau moyen de la mer, du géopotentiel, de la température et des composantes du vecteur vent. Pour le moment, ces statistiques sont toutes calculées et publiées en différé.

Abstract

The verifications done by CMC for its users cover the regions as defined in "The Monthly Review" and using the well known indices such as the S1, the bias, the root mean square deviation and the climatological anomaly. The one done in the context of the WMO project cover areas as defined below and using the S1 (referred as "Skill Score" by the WMO), the bias, the root mean square error and the correlation. These statistics are computed for fields of mean sea level pressure, of geopotential, of temperature and vector wind components. For the time being, these statistics are produced and published after the fact.

INTRODUCTION

Deux ensembles de vérifications des modèles de prévisions numériques du temps sont faites régulièrement au Centre météorologique canadien.

Dans un premier temps, les modèles canadiens, un certain nombre de modèles américains ainsi qu'un modèle spectral global du Centre européen pour la prévision à moyen terme sont vérifiés sur les régions canadiennes telles que définies dans "La revue mensuelle" et en utilisant des indices de vérifications dont la liste, les définitions et les particuliarités seront affichées au cours de l'Atelier.

Depuis le début de 1988, le CMC participe à un effort de l'OMM pour la vérification des modèles de prévisions numériques du temps selon les standards de cet organisme. Les vérifications au CMC sont faites contre les analyses pour l'hémisphère Nord et contre un réseau fixe de stations d'observation de radiosondage pour l'Amérique du Nord, l'Europe et l'Asie. Les Centres participants partagent les résultats de leurs vérifications et le CMC reçoit à chaque mois, ceux des Centres de Washington, de Bracknell et de Tokyo. D'autres Centres font des vérifications pour l'hémisphère Sud, les tropiques et la région de l'Australie/Nouvelle-Zélande.

LES VÉRIFICATIONS DU CMC

Nature des vérifications faites au CMC

La plupart des vérifications du CMC connues de nos usagers sont faites en différé, c'est à dire au cours du mois qui suit celui au cours duquel les prévisions ont été préparées. Bon nombre de celles-ci sont acheminées vers nos usagers au moyen du "Feuillet météorologique" ou de "La revue mensuelle" dans le ou les mois qui suivent mais il en reste un certain nombre qui sont disponibles au CMC et qui pourraient avoir un intérêt pour eux.

D'autres, par exemple des champs d'erreurs du géopotentiel ou des épaisseurs pour des prévisions de 12, 24, 36 et 48 heures vérifiant au même moment, sont disponibles en temps quasi-réel, c'est-à-dire au moment où l'analyse vérificatrice de ces prévisions est produite. Les valeurs du S1, du biais et de l'EQM pour chacune des régions du Canada seraient inscrites sur ces cartes. Ces vérifications pourraient êtres émises quotidiennement vers les bureaux d'exploitation.

Les vérifications sont faites deux fois par jour pour les prévisions de 12, 24, 36 et 48 heures vérifiant à 00z et 12z pour le modèle aux éléments finis et le modèle spectral ainsi que pour les modèles américains NGM et Global. Elles se poursuivent pour le modèle spectral à toutes les douze heures jusqua 72 heures inclusivement et une fois par 24 heures à 00z pour les prévisions de 96 et 120 heures. Le modèle global américain n'est pas vérifié à 60 heures mais ce dernier est vérifié une fois par jour à 00z pour 72, 96 et 120 heures et il en est de même pour le modèle du Centre européen mais à 12z.

Les modèles vérifiés et leurs grilles de vérification

En plus des deux modèles canadiens, soient le modèle régional aux éléments finis (CDNEFR) et le modèle spectral (CDNSPE), le CMC vérifie trois modèles américains. Ce sont: le modèle NGM ("nested grid model"), le modèle spectral global de la passe aviation du NMC (USGAV) et le modèle spectral global pour la prévision à moyenne échéance (USMRF). Enfin, des vérifications sont aussi faites pour le modèle spectral global du Centre européen pour la

prévision à moyen terme. En général, une grille stéréographique polaire de 762 km est utilisée sauf pour les modèles canadiens haute résolution où on utilise une grille de 190.5 km et une grille gaussienne de 64x32 pour la vérification de certains champs du modèle spectral.

Champs vérifiés et indices utilisés

Les champs vérifiés sont: la pression au niveau moyen de la mer, le GZ ou géopotentiel et le ΔGZ ou champ des épaisseurs, la température, les moyennes mensuelles des composantes U (E-O) et V (N-S) du vent.

Sur ces champs on calcul l'anomalie climatologique mensuelle (GZ), les valeurs journalières et mensuelles de l'indice S1 (GZ), de l'erreur moyenne (biais) et de l'écart quadratique moyen (GZ et température). Dans ces deux derniers cas le CMC utilise le décamètre et le degré Celsius comme unités de mesure et l'intensité du vecteur vent est donnée en noeuds. Plusieurs de ces résultats sont déjà mis à la disposition de nos usagers et d'autres pourraient être rendus disponibles selon l'intérêt manifesté.

LES VERIFICATIONS SELON LES STANDARDS DE L'OMM

Champs vérifiés et indices utilisés

Dans le cas des vérifications contre les analyses, on vérifie la pression au niveau moyen de la mer, le géopotentiel, la température et la vitesse du vent à 500 et 250 hPa. Les vérifications contre un réseau fixe de stations de radiosondage sont faites pour le géopotentiel, la température et la vitesse du vent à 850, 500 et 250 hPa.

Les indices de performance utilisés sont: l'erreur moyenne (biais), l'erreur quadratique moyenne, la corrélation et le S1 (appelé "Skill Score" par l'OMM). Le biais et l'erreur quadratique moyenne sont donnés en mètres pour le GZ et en degrés Kelvin pour la température alors que l'erreur quadratique moyenne du vent est donnée en mètres par seconde.

Pour les vérifications de l'OMM, les prévisions de 24 et 48 heures du modèle aux éléments finis et du modèle spectral sont vérifiées à 00 et 12z. Les prévisions de 72 heures du modèle spectral sont aussi vérifiées deux fois par jour mais une fois seulement pour les prévisions de 96 et 120 heures vérifiant à 00z.

Une bonne partie de ces résultats apparaissent dans "La revue mensuelle" soient sous forme de tableaux ou de graphiques.

CONCLUSION

Les vérifications faites au Centre météorologique canadien dont il est fait mention ci-dessus sont toutes produites en différé. Plusieurs résultats sous forme de cartes et de tableaux sont déjà apportés à l'attention de nos usagers par le truchement du "Feuillet météorologique" et de "La revue mensuelle". D'autres pourraient être ajoutés ou substitués à cet ensemble selon le désir des météorologistes dans les bureaux d'exploitation. Ce choix pourrait porter sur des vérifications pour des champs autres que le GZ ou la PNM, pour des vérifications en temps réel ou encore sur la préférence de voir des vérifications pour des prévisions ayant des heures de validité plus courte, par exemple, pour des prévisions de 24 heures au lieu de 36 et 48 heures. Le présent atelier est une bonne occasion de préciser cette préférence.

OBJECTIVE FORECASTS OF CLEAR AIR TURBULENCE POTENTIAL BASED ON DEFORMATION AND WIND SHEAR

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ABSTRACT

An objective forecast technique for clear air turbulence (CAT) is described. The index is the product of resultant deformation and vertical wind shear calculated from u and v wind components at numerical model grid points. It has been shown that this product contributes to frontogenesis, which in turn strengthens the vertical shear. Verification of the index for initial analysis and 24 hour forecasts were completed over the U.S. for the Nested Grid Model (NGM) produced by the National Meteorological Center (NMC). About 75% of 82 forecast turbulence events were correct while 33% were "false alarms".

Nous présentons une technique objective de prévision de turbulence en air clair. L'indice développé est le produit des cisaillements verticaux et de la déformation du vent calculés à partir des composantes u et v du vent aux points de grille de modèles numériques. Il a été démontré que ce produit contribue à la frontogenèse, qui en retour renforce le cisaillement vertical du vent. Nous avons vérifié des prévisions de 24 heures et des analyses pour les États-Unis et le "Nested Grid Model " (NGM) du "National Meteorological Center" (NMC). Près de 75% des 82 prévisons se sont avérées justes alors que 33% représentaient des fausses alertes.

INTRODUCTION

Numerous observational and theoretical studies since the 1950's have improved our understanding of clear air turbulence (CAT) substantially. Nevertheless, CAT is still a significant forecast problem today. Previous efforts to forecast CAT (excluding that caused by mountain waves) objectively have utilized either the non-dimensional Richardson Number and its time derivative (Brown, 1973; Keller, 1986) or vertical and horizontal wind shear (e.g., Dutton, 1980). This paper will describe a forecast index based on the product of horizontal resultant deformation and vertical wind shear.

BACKGROUND

Studies of animated satellite imagery beginning in the late 1970's showed that deformation zone cloud borders are often observed in the vicinity of significant CAT (Anderson, et. al, 1982). Deformation is a property of a fluid that results in compaction (deceleration) downwind and stretching in the crosswind direction. In the atmosphere, large deformation is associated with cols, shearing troughs and the exit region of jet streaks, as shown in Figure 1. Cloud borders form when hyperbolic flow patterns concentrate moisture along the stretching (dilatation) axis. This same process, along with convergence, works to strengthen horizontal temperature gradients with time near the cloud edge (shown in Figure 2). The result is an increase in vertical wind shear (from the thermal wind relationship), and a greater likelihood of CAT. Thus it was felt that quantifying the deformation and vertical shear would be a valid approach to the CAT forecast problem.

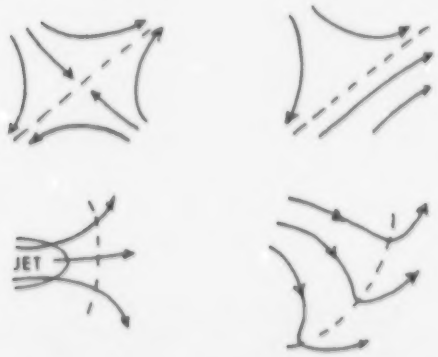

Figure 1. Upper level flow patterns associated with large deformation. The dashed lines indicate the usual locations of the axes of stretching (dilatation).

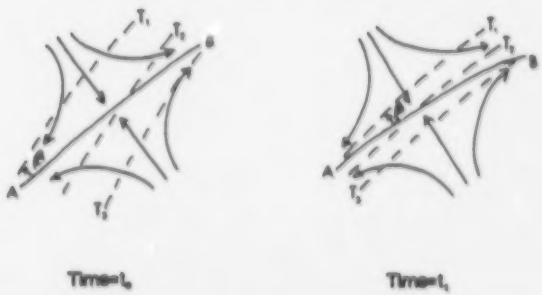

Figure 2. Strengthening of the horizontal temperature gradient with time in a region of deformation. β is the angle between the isotherms and the axis of dilatation (line A-B).

INDEX COMPUTATION

The deformation-vertical shear index (DVSI) for CAT is defined as:

$$DVSI = DEF \times VWS \quad (1)$$

where DEF is the resultant deformation and VWS the vertical wind shear. Resultant deformation is a kinematic property composed of two components, the stretching (DST) and shearing (DSH) parts (Saucier, 1955) which must both be considered. These components can be computed with u and v wind component data by the following equations:

$$DST = du/dx - dv/dy \quad (2)$$

and

$$DSH = dv/dx + du/dy \quad (3)$$

The resultant deformation is:

$$DEF = \sqrt{(DST^2 + DSH^2)} \quad (4)$$

The use of the product of DEF and VWS was first suggested by Mancuso and Endlich (1966), who found that it correlated well with CAT. This product is physically related to frontogenesis. The expression for the accumulation of temperature with time (A_t) on a constant pressure surface is:

$$A_t = .5\ fT/g\ (VWS)\ (DEF - DVG)\ \cos\phi \quad (5)$$

where f is the Coriolis parameter, T is temperature, g is gravity, DVG is divergence and ϕ is the angle between the isotherms and the axis of dilatation. When the flow is convergent, DVG is negative, resulting in a positive contribution. Normally, however, DVG is quite a bit less than DEF, so it can be neglected in most cases, especially when numerical model forecast data is used.

DATA SOURCES AND FORECAST PRODUCTION

The source of forecast u and v wind component data used in the production of the DVSI is either the Nested Grid Model (NGM) or the global Aviation Model (AVN) produced twice daily by the National Meteorological Center (NMC) in Washington, DC. The model data is automatically transferred to the VAS Data Utilization Center (VDUC) computer system, where the DVSI is produced using on-line programs. The running time of the DVSI program is generally less than 30 seconds. Forecasts for the 12 and 24 hour periods have been produced on the VDUC almost continuously since the Fall of 1988.

Values of DEF are computed at the 300mb standard pressure level. The VWS is the resultant vector shear for the 300 to 400 mb layer. This layer was chosen because it often captures the maximum vertical shear near the jet stream during the colder months of the year. Jet aircraft often cruise at a higher altitude than this, so the DVSI may not always be representative of conditions reported by the aircraft.

The DVSI was first produced for NGM initial analyses as a check to see how well the index represented actual conditions. Later, the 24 hour forecasts from the NGM were verified. It was felt that this was the forecast period most useful in operations, considering the time lag in obtaining the data. Subjective aircraft turbulence reports were used to evaluate the index. The reports are computer plotted in 6 hour intervals for NMC's Monitoring and Aviation Branch. Due to communications difficulties, there are few reports obtained from Canada. The DVSI was also compared to GOES infrared (IR) or water vapor (WV) satellite imagery at the verifying time to determine how maxima related to significant cloud features.

EXAMPLES

November 16, 1987

The 6 hour forecast DVSI analysis derived from the NGM model valid 1800 UTC, November 16, 1987 is shown in Figure 3. Reports of moderate and severe CAT within 3 hours of the valid time are superimposed. Index values are in units of 10^{-7} sec^{-2}. An empirical threshold of 4 has been determined to outline regions of significant turbulence threat using the NGM model. Values of 8 or more usually denote a high risk of moderate or severe CAT. A maximum DVSI of 12 in the central United States on this afternoon indicates a high risk area for CAT. Numerous reports of moderate to severe turbulence were received for this period, enclosed mainly within the 4 contour. Turbulence which occurs in areas of thunderstorms (such as within the dashed line in the lower Mississippi Valley) is not accounted for by this technique, nor is CAT produced by mountain waves. A second area of CAT in the northern Rockies that was not attributed to mountain waves verified fairly well.

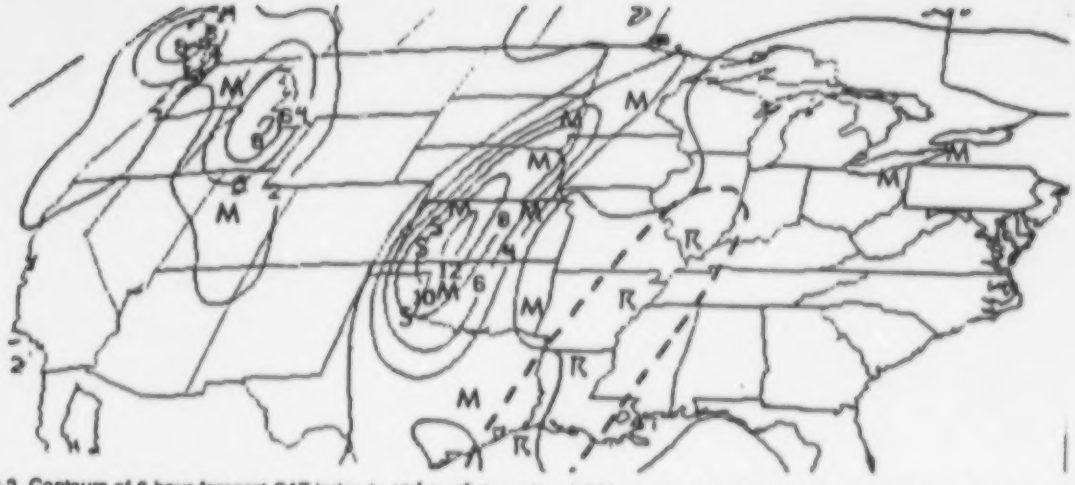

Figure 3. Contours of 6 hour forecast CAT index (x 10^{-7} sec^{-2}) based on NGM model valid 1800 UTC, November 16, 1987. Reports of severe (S) and moderate (M) turbulence within 3 hours of valid time are shown. Turbulence resulting from thunderstorms occurred within dashed line.

December 28, 1989

A severe test for any objective forecast is over mid-ocean regions where data is sparse. Unless a weather system originates over land, much of the initial analysis must be obtained from radiometric satellite data from the polar-orbiting NOAA satellites. On December 28, 1989 at 0000 UTC, a rapidly moving frontal system had reached the central Atlantic between 25W and 40W and north of 40N. Figure 4 shows a Meteosat infrared image remapped to the Polar Stereographic projection valid at 0300 UTC, December 28.

The 24 hour forecast DVSI from the AVN model valid at 0000 UTC, December 28 is shown in Figure 5, with turbulence reports superimposed. A threshold of DVSI=2 usually represents a lower limit for significant turbulence using the AVN model. The difference in thresholds for the two models is attributed to differences in grid point spacing. The forecast verified well, considering that some of the severe turbulence at 20W occurred 4 to 5 hours after the valid time. It appears, however, that considerable CAT occurred slightly north of the forecast maximum area. To explain why this happened, we need to look at additional information.

The 24 hour forecast 300mb winds and isotachs shown in Figure 6 indicate a strong jet extending from near 42N 50W to a ridge axis near 46N 35W, which then turns abruptly southeastward. The upper flow is strongly diffluent near the ridge, suggesting large deformation. Figure 7 shows the 24 hour forecast of DEF (solid lines) and VWS (dashed lines), the two components of the DVSI. Maximum DEF is slightly north of the VWS maximum, in better agreement with observed turbulence. Where the two maxima overlap, the DVSI should be largest; this agrees with Figure 5. A look at the satellite image (Figure 4) reveals a brightness gradient within the cloud band (arrow), suggesting a rapid change in cloud top temperatures (thus cloud height). This feature usually marks the location of the upper jet. The maximum winds (and shear) at 0300 UTC should thus lie along a line from 40N 45W to the ridge axis at 53N 30W. Even when the later image time is considered, the jet is still about 5 degrees north of the forecast position and accounts for the displacement in the DVSI forecast. The initial analysis for the AVN at this time (Figure 8) is more representative, showing the jet farther north, and a slightly sharper upper ridge. This case demonstrates the value of satellite imagery in updating objective turbulence forecasts.

VERIFICATION

The DVSI was verified using probability of detection (POD), False Alarm Ratio (FAR) and Critical Success Index (CSI) as defined by Weiss (1977). These statistical properties are used by the National Severe Storms Forecast Center (NSSFC) in Kansas City for verifying severe thunderstorm forecasts. In this study, a threshold of DVSI=4 was used to define areas of forecast CAT over the U.S. using the NGM model. A minimum of 2 or more reports of moderate or greater CAT within 3 hours of the valid time were required to verify each area, and to identify CAT "events" that were unforecast. Turbulence attributed to mountain waves or thunderstorms were not included. Table 1 shows the results of the verification for both initial analysis data and 24 hour forecasts. The POD, a measure of how well the TI detects CAT events, was in the 70-75% range. The FAR, which indicates the tendency for overforecasting CAT, increased from 20% for the analysis to 33% for the 24 hour forecast. To place these numbers in perspective, tornado watches issued by NSSFC from 1982-88 had PODs of 71% for significant tornadoes and 35% for all other tornadoes (Hales, 1989). The FAR figures for the DVSI are undoubtedly high considering the difficulty in obtaining reports in some situations. Aircraft often change altitudes or alter routes to avoid turbulence regions once they are reported.

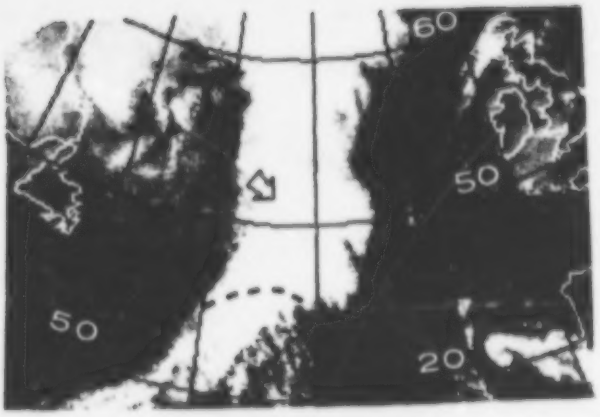

Figure 4. Meteosat IR image remapped to polar stereographic projection at 0300 UTC, December 28, 1989. Arrow refers to change in cloud top brightness relating to jet stream crossing point. Dashed line is forecast position of jet stream.

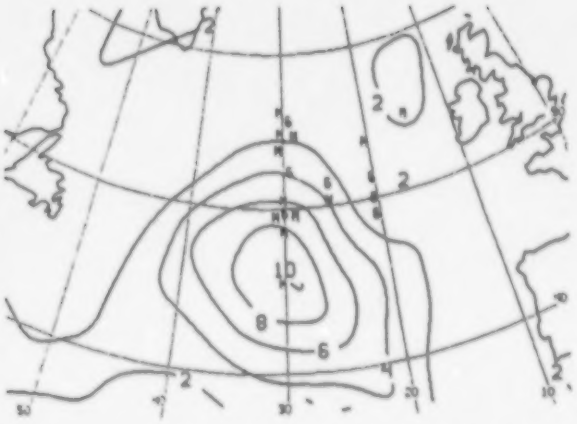

Figure 5. Same as Figure 3 except for AVN 24 hour forecast valid 0000 UTC, December 28, 1989.

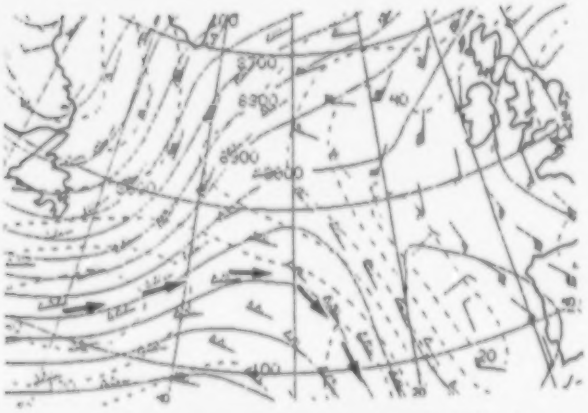

Figure 6. 24 hour forecast 300mb winds, isotache (dashed lines) and pressure heights (solid lines) from AVN model valid 0000 UTC, December 28, 1989. Large arrows show jet stream axis.

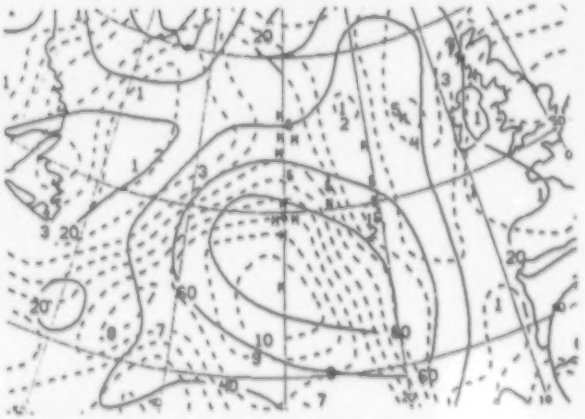

Figure 7. 24 forecast of resultant deformation (DEF) at 300mb and vertical shear (VWS) from 400 to 300mb from AVN model valid 0000 UTC, December 28, 1989.

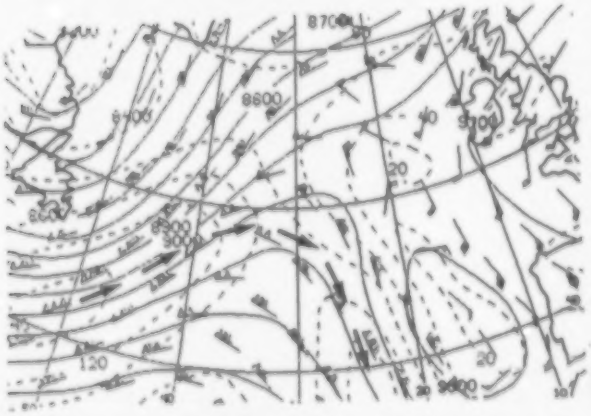

Figure 8. Same as Figure 6 except for AVN analysis at 0000 UTC, December 28, 1989.

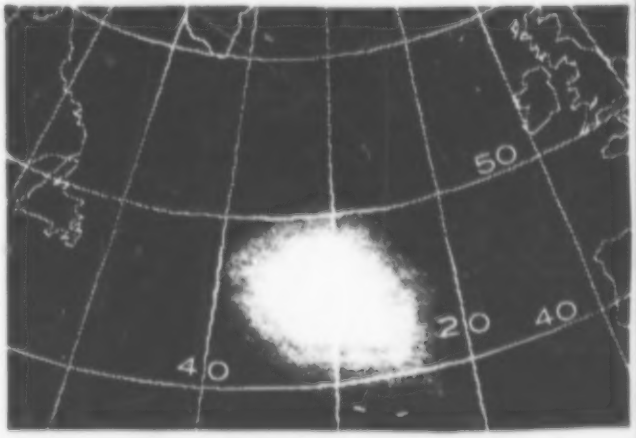

Figure 9. Pseudo image created from 24 hour forecast of DVSI (Figure 5).

Table 1.
VERIFICATION OF CAT INDEX

	Initial NGM	24hr Forecast NGM
Maxima ≥4	71	82
Correct Forecasts (x)	57	55
Incorrect (z)	14	27
Unforecast Events (y)	24	17
Prob. of Detection (POD) (x/x+y)	70%	76%
False Alarm Ratio (FAR) (z/x+z)	20%	33%
Critical Success Index (CSI) (x/x+y+z)	60%	56%

OPERATIONAL USERS

In addition to NMC, the U.S. Air Force's Global Weather Center (AFGWC) in Omaha will begin using the DVSI in their worldwide forecast operations around April 1, 1990. Their index has been modified to include effects of convergence in the upper flow. Preliminary verification at AFGWC indicates that 83% of the forecast CAT areas for the 300-500mb layer verify. The National Aviation Weather Advisory Unit (NAWAU) in Kansas City expects to be able to evaluate the DVSI, once numerical model forecast data become available to them. NAWAU is responsible for domestic aviation area forecasts (FAs) and significant hazard advisories (SIGMETs).

ONGOING WORK AND FUTURE APPLICATIONS

Further verification of the DVSI is underway using AVN model forecasts. An evaluation of forecast skill similar to that completed for the NGM is planned over the U. S. and possibly some of the more heavily-traveled oceanic routes. Statistics on frequency of occurrence and cumulative frequency are being collected for all index values in order to provide probability guidance for forecasters. Further study of the index is needed to identify situations where poor forecasts often occur. For example, the recent elimination of Mexican radiosonde data in the NMC analyses has already resulted in at least one case of an undetected upper level jet maximum which resulted in unexpectedly strong CAT. Intercomparison with other forecast techniques would also be desirable.

Modern computer display systems such as VDUC (and most McIDAS-type systems) are capable of converting gridded forecast information into a pseudo image display. When a series of such images are animated and color enhanced to highlight significant values, it becomes much easier to interpret forecast trends, especially over a large area. Figure 9 is an example of a DVSI image for the December 28, 1989 case described above. Other applications of this type of display are possible, such as in the study of the global dissipation of kinetic energy.

It has also been demonstrated that the DVSI can be produced from satellite-derived winds with reasonable results (Ellrod, 1989). Winds from remote sensors such as satellites, profilers and Doppler radars could provide useful updates to objective forecasts.

SUMMARY AND CONCLUSIONS

An index has been developed for the forecasting of clear air turbulence which is based on deformation and vertical wind shear derived from forecast winds aloft. Based on experience so far, the technique is fairly reliable. It correctly forecasts about three-fourths of observed turbulence events. Some false alarms do occur, although probably not as many as the one-third figure obtained in the verification study. More widespread dissemination of raw numerical model forecast data (such as wind components) can be expected in the future, which will permit the development and use of many new types of forecast techniques such as the one described here. For example, NMC transmits gridded binary (GRIB) forecast winds aloft and temperatures on international communications lines. While the forecasting of clear air turbulence may never be perfected, the steady improvement of forecast models provides considerable hope for the future.

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WEATHER ELEMENT FORECASTS USING RULE BASED SYSTEMS

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ABSTRACT

This paper will discuss the rule base structure of automated weather element forecast systems and how further rule based structuring can be added to improve the forecasts. In general, the rules that are followed parallel those that the forecaster uses or has used. The basic input may be from statistical forecasts or direct model output. A learning or a knowledge acquisition system is included, where, through post processing, information based on previous verifications can be fed back to get new improved forecasts. The combination or merging of forecasts makes the decision when several alternatives are available and produces improved forecasts.

RESUME

La structure de systèmes basés sur des règles des techniques de prévision d'éléments du temps automatisées sera examinée ainsi que la façon d'additionner d'autres systèmes basées sur des règles pour améliorer les prévisions. En général, les règles qui sont utilisées sont semblables aux règles utilisées par un prévisionniste lorsqu'il fait des prévisions. Les données d'entrée pour le système peuvent provenir de prévisions statistiques ou être prisent directement d'un modèle numérique. Un système d'apprentissage y est automatiquement inclu où, par l'entremise de techniques de post-traitement, l'information basé sur des vérifications antérieures peut être réintégré pour produire des nouvelles prévisions améliorées. Quand il y a plusieurs alternatifs, la technique de combinaison des prévisions prend automatiquement la meilleure décision possible.

1. INTRODUCTION

Rule based systems in one form or an other have long been used in the forecasting of various weather elements. In the pre numerical weather prediction (NWP) era, knowledge of synoptic systems, air mass characteristics and extrapolation techniques played a dominant role in the forecast formulation. When electronic computing power began to develop rapidly in the 1950's and Numerical Weather Prediction products became available, techniques were developed to relate NWP output to weather elements. These techniques basically tried to simulate what the forecaster did. The statistical techniques produced a form of "instant climatology" or "instant experience" and provided the forecaster with tools and automated rules to use to interpret model output. In this sense, all statistical forecasts are rule based systems, the rules being automatically defined.

Post processing techniques are another example of rule based systems that can help to update and improve statistical forecasts. Information based on previous verifications can be fed back to get a new forecast set. Through the merging of forecasts from different techniques, the use of calibration and error feedback techniques, biases and errors may be reduced and the forecast distribution improved. The results of the applications of some of these post treatment techniques will be shown in this paper.

2. STATISTICAL- DYNAMICAL WEATHER ELEMENT FORECASTS

As electronic computing power began to advance rapidly in the 1950's and following decades, there was remarkable progress in the numerical/dynamical prediction of atmospheric circulation. Widespread use of model output in weather element prediction was made in the perfect prog method (PP) (Klein et al, 1959) and in the model output statistics (MOS) (Glahn and Lowry, 1972) approach. Local effects were introduced implicitly, using resolution not available to the direct model approach. Verifications of the PP maximum temperature forecasts(Brunet and Yacowar 1982) for the cold season, November to April prepared at the CMC show continued increase in skill over climatology over the past two decades. The verifications based on the 00Z cycle are shown in figure 1. Skill

scores increased about 15 percentage points for the day one period and about 25 points for the day 3 period. The skill score indicated is given by

$$SS = \left(1 - \frac{(F-O)}{(C-O)}\right) \times 100$$

where F is the forecast value, O is the observed value and C the climatological forecast.

Considerable improvement has been made in tuning models to directly produce surface weather element forecasts. However, to this date the statistical forecasts continue to show a marked improvement over direct model output and provides the justification for continued development and improvement of statistical forecasts. The comparison of direct output from the Canadian Spectral Model with 59 waves and 15 levels and PP produced spot time temperature forecasts (Brunet, 1987) out to one hundred and forty four hours is shown in figure 2 for 173 Canadian stations for the cold season, November 1988 to April 1989. The statistical PP forecasts have skill scores that are about 20 percentage points higher than the model forecasts. The PP forecasts show skill beyond 144 hours, the model forecasts show skill to 108 hours. The PP forecasts extend comparative skill range by well over 30 hours. The statistical forecasts show an improvement in mean absolute error between one half to one degree Celsius for all time periods.

Further improvements are possible in development of statistical forecast systems. In most of the systems, relationships were developed using all the historical data in one data set and predictors were chosen according to climatological predominance. The forecaster does not necessarily use fixed rules but selects his rules on the basis of circulation regimes. Surface observations at input time are used as predictors in various predictive schemes. The ideal approach, which the forecaster uses, is to recognize where upstream information may be found for various projection times. Under current statistical schemes the upstream station chosen is one which is the "climatological upstream " station. Observations at North Bay Ontario or stations in the general vicinity are often chosen as predictors for Montreal, specially for projections under sixty hours. Seven times out of ten North Bay will be the ideal upstream site. Under abnormal circulations, however, this choice put's the forecast system in jeopardy.

In general, stability indices are not selected as predictors for precipitation occurrence since precipitation may be associated with unstable air mass conditions as well as with stable air associated with frontal systems and over running. As predictors, the stability indices will be wiped out, the effects cancelling out. Winds may have contrary affects, North winds are usually associated with cold advection and below normal temperatures. Conversely, a strong northerly wind, because of the mixing affect, might prohibit drastic night time cooling. The stratification of the development data, according to baroclinicity or circulation patterns, might permit a more discreet selection of predictors.

Originally, most regression systems used predictors in a linear form.A non linear representation of predictors is required so that the transformed predictors have a frequency distribution that more closely represents that of the forecast element. The frequency distribution of observed occurrence of precipitation at several Maritime stations and the forecast value of the maximum relative humidity at 70 kPa for the period 24 - 36 hours after input time is shown in figure 3. The transformed predictor would show nearly equal values for all relative humidities below 30, another nearly equal set for values above 80 % with some linear fit for other values. The enhancement of predictors through combinations (multiplications, additions etc) with other predictors may often provide a better fit with the predictand than the predictors taken individually. Transformation and enhancement techniques were used in the development of the CMC MOS probability of precipitation (POP) forecast system (Yacowar et al 1985). One example of this is a predictor developed by using the product of scaled relative humidity and vertical motion predictors.

3. POST PROCESSING TECHNIQUES

Post processing techniques are another example of rule based systems that can help to update and improve statistical forecasts. The object is to make the post sample products resemble observations. Information based on previous verification can be fed back to get a new forecast set. With error feedback, bias may be removed, errors reduced, and forecast distribution improved. Recent changes in the operational model may also be incorporated into the forecasts.

Inflation factors and have been incorporated in statistical wind forecasts as a means of forcing the equations to predict away from the mean in order to catch some of the important extreme windspeeds. The opposite consideration is required as the projection time increases and the reliability of the models decreases. Deflation techniques are used at the CMC to reduce the forecast maximum and minimum and spot time temperature anomalies (Brunet, 1988). The anomaly reduction depends upon and increases with projection time and the anomaly value. A maximum of 45 % anomaly reduction is allowed. At twenty four hours the forecast remains unchanged, the reduction effect being more pronounced at longer projection times. For spot time temperature forecasts beyond 72 hours, improvements in skill scores of 5 to 15 percent are noted. The anomaly deflation used for the maximum and minimum temperatures is shown in figure 4. Improvements in skill score of 10 to 35 percent are noted for the day 3-4-5 period.

Deflation is also applied to the POP forecasts for the twenty four hour period for days 4 and 5 (Soucy and Yacowar, 1986). The POP anomaly (departure from normal) is reduced by 10 percent on day 4 and 20 percent on day 5 resulting in increased Brier Scores with respect to climatology of 2 to 5 percent.

An auto-correction system for perfect prog POP and opacity forecasts has been developed and implemented at the CMC (Verret 1989) based on the verifications during the previous 90 days. The forecast errors are found and feedback corrections are calculated and fed back into the forecasts for each station at each projection time. This system allows the PP forecasts to take on some of the attributes of forecasts produced by a MOS technique. The skill scores and distributions are improved and the mean errors reduced for all projection times. Improvement in the Heidke skill scores are in the order of ten percent and are shown in figure 5.

4. COMBINATION OF FORECASTS

In many domains of decision making there may be information available from different sources. When a decision maker is interested in the outcome of some chance event, he may solicit information from one or more sources. Should he toss a coin to decide which scheme to use or is it possible to take advantage of the information contained in all of the available systems. Thompson (1976) draws attention to the incontrovertible fact that two or more inaccurate but independent predictions of some future events may be combined in a very specific way to yield predictions that are on the average, more accurate than either or any of them taken individually.

Several authors have shown that consensus forecasts produce better results than individual efforts. Studies of forecasts made at the Massachusetts Institute of Technology (Sanders, 1973) indicated that the consensus forecasts of participants on the average produced better results than the forecasts prepared by individual forecasters.

For many elements, several forecast production systems may exist. These may include Multiple Linear Regression, Multiple Discriminant Analysis or Analog derived systems based on Perfect Prog or Model Output Statistics input data. All of these may have value or special attributes, whether it is accuracy based on skill scores or sharpness, reliability and detection possibility. The advantages attributed to MOS are that it can partially account for consistent model biases and reflect the accuracy of the driving model. MOS has access to predictors that are not available in a PP system. The advantages of the PP system include the stability of the equations due to larger development samples. The PP system is model independent and less costly to maintain.

While forecasts from different techniques are highly correlated, since they are based on the same model output, some independence exists. Using calibration techniques (Clemen and Murphy, 1986) it was shown that PP forecasts add information to the MOS forecasts and vice versa.(Verret, 1988). The calibration of MOS and PP probability of precipitation forecasts are shown in figure 6. The observed frequency of precipitation varies with the MOS forecast, even if the PP forecasts remain fixed. As an example, when the PP forecast is fixed at 80%, the observed frequency of precipitation is 40% with MOS forecasts of 40% and climbs to 84% with MOS forecasts of 80%. The inverse is also true when the PP forecasts are calibrated on the basis of the MOS forecasts. The differences in MOS and PP spot temperatures are shown in figure 7. On the average, 25% of the PP and MOS spot time forecasts produced at the CMC differ by two degrees Celsius or more. This percentage varies from 10% in the summer to as high as 40% in the winter. Further discrimination on availability of information may be based on the ranges forecast, with the weights assigned depending on the range forecast. The calibration of PP and MOS spot temperatures is shown in figure 8. The ranges for much above and much below normal are for temperatures with anomalies greater than +/- 7 deg C. Normal temperatures were considered in the range 2 to -2 deg C. Above and below normal temperatures are in the ranges 3 to 7 and -3 to -7 deg C. The calibration is made for all of the PP forecasts in the "normal range". The verifications are for the cold season, 1988-89 for a region covering the Prairie Provinces. When MOS forecasts were for below normal temperatures, the frequency distribution of observed temperatures was skewed towards below normal temperatures. The opposite effect was observed when the MOS forecasts were for above normal temperatures. Extra information can be added to the PP forecasts by the MOS forecasts and vice versa.

In the current procedures at the CMC,(Verret and Yacowar, 1989) rule based systems were developed to extract the best information from several competing independent forecast systems. Contingency tables were prepared to show the tri-variate distribution of two forecast systems and the verifications. The forecasts were combined systematically to arrive at the best final product. The objectives were to minimize the post-sample forecasting errors, to increase the sharpness and detection possibility of the final forecasts and to ensure consistency between forecasts of different weather elements.

A rule based forecast combination system was designed to merge the MOS and PP forecasts at the six and twelve hour periods. The resulting six and twelve hour forecasts are then adjusted to ensure consistency and increase sharpness. Verifications of the final product, called the PP union MOS (PUM) forecasts show higher Brier Skill Scores with respect to climatology as shown in figure 9. The PUM forecasts have skill scores that are at least five percentage points better than the best of the competing MOS and PP forecasts. The PUM forecasts also show an improved sharpness compared to the original MOS or PP forecasts and a reliability which is as good as the better of the two original forecast sets.

Probability of precipitation forecasts over twenty four hour periods using analog techniques, are used at the CMC to produce computer worded forecasts for the day three to five period. The merged Analog /MOS forecasts based on independent data showed higher skill scores and sharper forecasts.

Spot time temperature forecasts at three hour intervals are produced by merging MOS and PP forecasts, using a simple averaging of the two forecasts. The verifications out to 84 hours are shown for the cold season, November 1988 to April 1989 in figure 10 in terms of percentage improvement over climatology. The PP forecasts are superior to the MOS forecasts for the early periods, the MOS forecasts are equivalent or somewhat better than the PP forecasts in the later periods. For the very short term the combined forecasts are equivalent to the PP forecasts. Beyond eighteen hours the combined forecasts show higher skill than either of the original forecast sets. Discrepancies are noticed on inspection of regional or individual station verifications.

The combination techniques used at CMC in general use relationships that apply to the total station set for all projection times for all forecast ranges. In view of the initial success with a

simplistic approach, the techniques will be refined to apply to regions or individual stations for each projection time with particular attention paid to forecast ranges.

It is common in forecasting practice to relate one forecast element to another. Brunet (1988) attempted to determine the effects by relating forecast temperatures to observed winds, sky cover, precipitation and the actual temperatures at the valid projection time. Although these elements may be available implicitly as predictors in a regression equation, new weights were found. When these weights were applied to real forecast data, no improvement was noticed. This was due to the unreliability in the actual forecasts of precipitation, cloud and wind. These tests were based on the total station set. Further tests will be carried out based on stratification of synoptic types. The verifications may then indicate under which conditions to use feedback from one forecast element to another.

One missing link that has not been taken advantage of is input from the field forecasters. Many forecast rules, based on experience, knowledge of local conditions and when and how to use the guidance material under different conditions (Ricketts, 1987) have been developed for individual stations. These rules should be incorporated into the automated guidance system and could make a major contribution towards improved forecasts.

CONCLUSION

While direct model output of weather element predictions has improved, the level of performance still remains below that attained by various rule based statistical applications, reaffirming the need for continued effort in improving the rule based statistical systems. Post treatment of forecasts, through inflation or deflation techniques and error feedback produces the effect for which they were designed, increased skill, better sharpness and better forecast distribution. It has been shown that combination techniques when applied to forecasts from different sources produce forecasts with higher skill scores and better resolution. The post treatment techniques , using rule based systems, offer advice, make decisions and solve problems that might require years of experience for individual forecasters. The reasoning process is based on a learning approach which takes into account previous evaluations. This system may be easily automated to give continual feedback and produce updated weights based on the most recent observations and verifications.

Further refinements are being considered both in the development of statistical models and in post treatment techniques. Further stratification of data is necessary and post treatment based on the individual station, individual projection time and the specific forecast range may prove useful. Decision tree approaches can be developed to incorporate the statistical forecasts. Full advantage should be taken of rules developed and used by operational forecasters and made part of the operational system with the objective of improving weather element forecasts.

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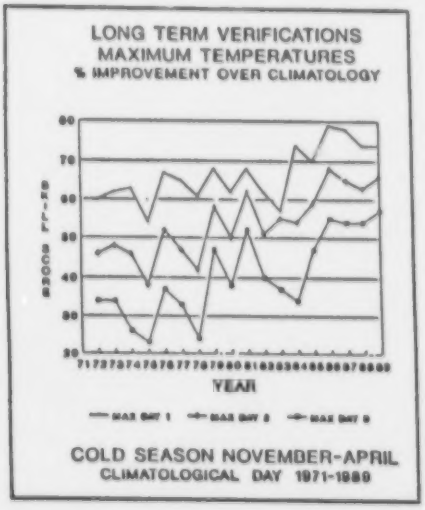


Figure 1: Long term verifications of maximum temperatures for days 1 to 3 based on the 00 UTC cycle. The skill scores in terms of percent improvement over climatology, using a quadratic scoring rule are given for the cold seasons, November to April from 1971 to 1989.

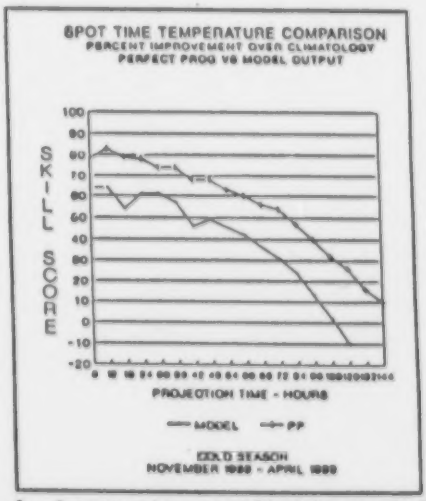


Figure 2: Comparative verifications of PP and the direct spectral model output of surface temperatures at spot times in terms of percent improvement over climatology based on the 00 UTC cycle. Verifications are for the cold season, November 1988 to April 1989.

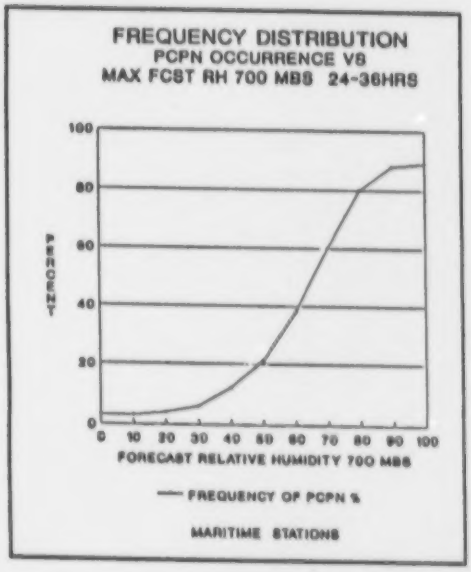
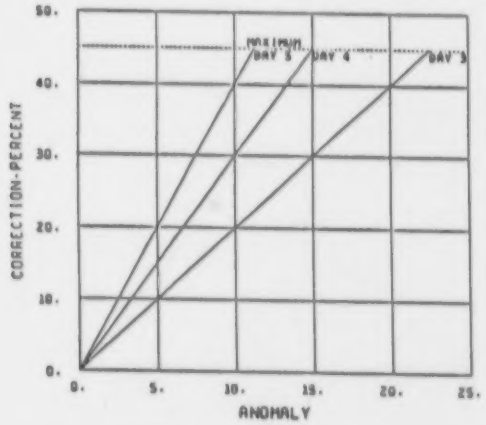


Figure 3: Frequency distribution of precipitation occurrence relative to the 24-36 hour forecast relative humidity at 70 kPa. The maximum forecast relative humidity is used in the 24-36 hour period. The distributions are for maritime stations during the cold season.



ANOMALY DEFLATION

$$ANOM' = ANOM - \frac{COR \times ANOM}{100.}$$

Figure 4: Anomaly deflation used for maximum and minimum temperature forecasts for days 3 to 5. The anomaly reduction depends on the forecast anomaly value and the projection time. A maximum deflation of 45% is allowed.

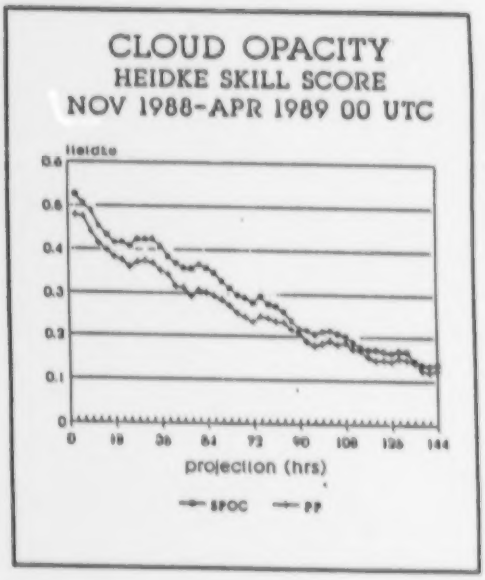


Figure 5: Comparison of the auto-corrected (SPOC) forecasts of total cloud opacity with the original PP forecasts. Verifications were made for 173 Canadian stations in the 00 UTC cycle for the period November 1988 to April 1989.

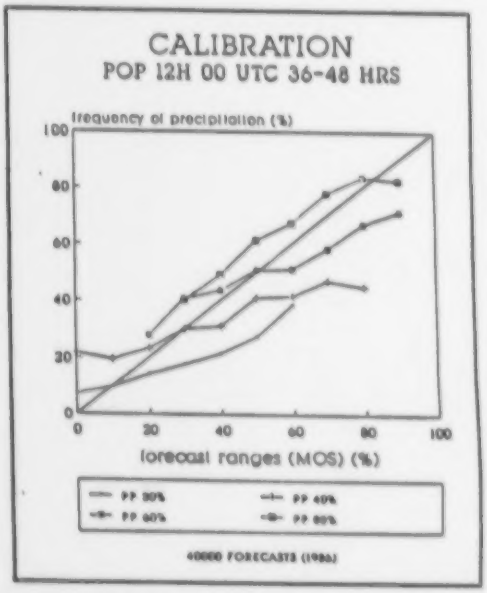


Figure 6: Calibration of the MOS 36-48 hour POP forecasts relative to the PP forecasts over 12-hour periods. The PP curves correspond to the calibration of the MOS forecasts when the PP forecasts are set at 20, 40, 60 and 80%. The sample consists of forecasts produced at 134 Canadian stations during 1986 based on the 00 UTC cycle (approximately 40,000 forecasts).

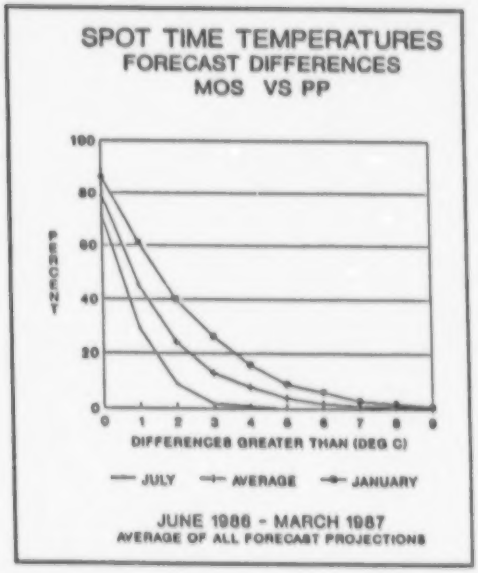


Figure 7: Differences in MOS and PP spot time temperature forecasts averaged over all projection times out to 60 hours. The percent differences are shown for a summer and winter month and for the average value for 173 Canadian stations for the period June 1986 to March 1987.

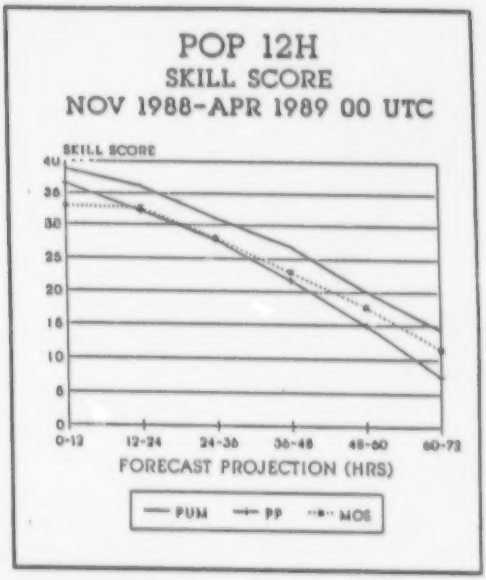


Figure 9: Skill scores with respect to climatology of the original MOS and PP forecasts and of the merged PUM forecasts of probability of precipitation over twelve hour periods. Verifications are for 173 Canadian stations in the 00 UTC cycle from November 1988 to April 1989.

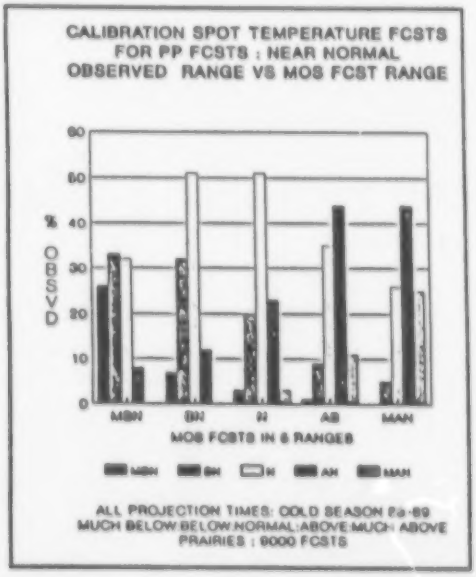


Figure 8: Calibration of PP spot time temperature forecasts in the near normal range relative to the MOS forecasts in 5 ranges, much below normal, below normal, near normal, above and much above normal. The frequency distribution of the observed temperatures in the five ranges are shown for all of the PP forecasts in the near normal range. Verifications are for stations in the Prairie Provinces (9000 forecasts) for all projection times out to 60 hours for the period November 1988 to April 1989 in the 00 UTC cycle.

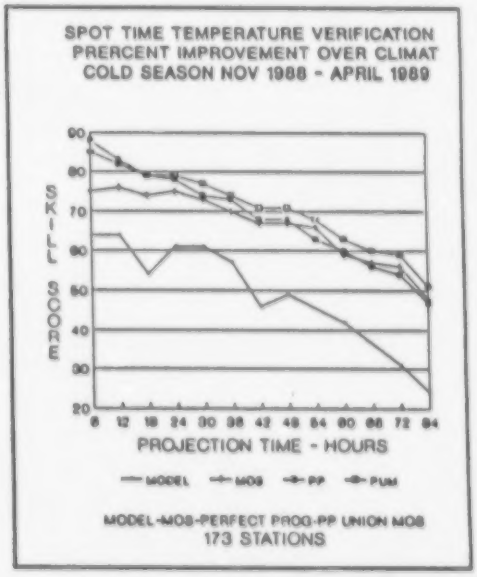


Figure 10: Skill scores for the original MOS, PP, and merged PUM spot time temperature forecasts as well as those available directly from the model. Verifications are shown out to 84 hours for 173 Canadian stations in the 00 UTC cycle for the period November 1988 to April 1989.

STATISTICAL MESOSCALE FORECAST GUIDANCE FOR 24-HOUR LAKE-EFFECT SNOWFALLS USING "CART"

by

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ABSTRACT

Lake effect snowfall possible (LESP) days were identified for each of 29 climatological stations in the lee of Lake Huron and Georgian Bay for the November to April winters of 1984-1988. Identification was done with 0-24 hour (Day 1) and 24-48 hour (Day 2) forecasts by 1200Z runs of the CMC spectral operational NWP model. Twenty-four hour snowfall data on LESP days was separated into 5 categories: 0-trace, >trace-5cm, >5-12.5cm, >12.5-22.5cm, and >22.5cm. The data implies "broad brush" areal forecasts of snow amounts stand a significant chance of being wrong for individual stations and small areas, even in the heart of the "snowbelt". Potential predictors designed to accomodate the 24-hour period of the predictand were calculated from the NWP model data on a 65 km interpolated grid. A recent non-parametric classification procedure known as "Classification and Regression Trees (CART)" was used to make decision trees. The CART-based model-output statistics (MOS) method described here shows considerable promise for production of useful objective operational meso-scale guidance for 1 and 2 day forecasts of lake-effect snow. The most important predictors involved low-level divergence (convergence) at nearly every station.

Les jours avec possibilité d'accumulation de neige due aux grains de neige formés sur les Grands-Lacs (LESP) ont été identifiés pour les 29 stations climatologiques le long du lac Huron et de la baie Georgienne de novembre à avril des années 1984 à 88. Nous avons considéré les prévisions du jour 1 et du jour 2 faites avec le modèle spectral canadien émises à 12Z. Les précipitations de 24 hres ont été divisées en 5 catégories : 0-trace, trace-5cm, >5-12.5cm, >12.5-22.5cm et >22.5cm. Les résultats démontrent que les prévisions synoptiques ont de fortes probabilités d'être fausses pour les stations prises individuellement Nous avons calculé les prédicteurs potentiels tirés du modèle numérique sur une grille interpolée de 65 km. Une procédure de classification non-paramétrique (CART) a été utilisée pour faire des arbres de décision. Les résultats statistiques utilisant CART et une approche MOS, décrite dans le texte, indiquent que la méthode est prometteuse pour la production d'aide numérique objective à mésoéchelle pour cet effet de lac. Le prédicteur le plus important était la divergence (convergence) de bas niveaux à presque toutes les stations.

1. INTRODUCTION

Lake effect snowfall is one of the challenging meso-scale forecast problems around the Great Lakes - on occasion more than 30 cm of snow has fallen in a 24 hour period over small areas. To date there is little objective operational guidance available to forecasters, perhaps due to the meso-beta scale of lake-effect snow being below the resolution of current operational Numerical Weather Prediction (NWP) models. Present forecast procedures in operational weather offices generally rely on subjective manual or semi-computerized interpretation of model output fields using a variety of decision tree methods and accumulated office experience (e.g. Dockus (1985), Niziol (1987), Murphy (1989)). While several observational and research studies using meso-scale models have appeared in the literature, these have not (to the author's knowledge) led to production of regular objective forecast guidance in the field. The only known published "model output statistics (MOS)" approach to providing objective forecast guidance for lake-effect snow (Dewey, 1979a,b) was never implemented.

A study was undertaken by Burrows (1990) to examine the feasibility of providing objective mesoscale forecast guidance for lake-effect snow for up to 48 hours projection time for the Georgian Bay region. In that study, "Perfect Prog (PP)" forecasts of 5 possible categories of 24-hour snow amount were produced using multiple discriminant analysis (MDA). The forecasts were "tuned" with an independent data base using the MDA probabilities as predictors by a recent statistical classification procedure known as Classification and Regression Trees (CART) developed by Brieman et al (1984). CART searches a predictand-predictor data base for decision tree rules by which to classify a predictand according to predictor values. It is non-parametric in that it makes no assumptions about the distribution of the predictors, and it considers individual predictors offered to it plus linear combinations of predictors.

It was suggested in the above work that while the forecasts lacked sufficient accuracy to be useful as guidance, there was considerable promise that more accurate forecasts could be generated if a better predictor set were designed, if NWP model output data were used for derivation of predictors instead of analyzed observed data (i.e. MOS approach instead of PP approach), and if the CART procedure were more fully utilized. This paper describes the subsequent work that has been done.

2. DATA

For the predictand, daily snowfall data for the winters of 1984-1988 (November 1 -April 30 except to March 25, 1987 and April 8, 1988) were gathered for the 29 climatological stations to the lee of Lake Huron and Georgian Bay (henceforth abbreviated as LH and GB, respectively) shown in Figure 1. A climatological day is defined as 8am today to 8am tomorrow. The total number of days without missing data during the study period ranged from a low of 600 to a high of 643, with about 633 days available at many stations. The data set was screened at each station to separate out "lake-effect snow possible" (LESP) days, defined as at least 12 hours of a 24 hour period that the Canadian Meteorological Center (CMC) spectral NWP model had forecast a local over-water 850 mb wind fetch and a lake-850 mb temperature difference of at least 13 degrees C, or 8 to < 13 degrees with upward vertical motion at 700 mb. Snow amount in cm at each station was divided into 5 categories: 1= 0-trace, 2= >trace-5, 3= >5-12.5, 4= >12.5-22.5, 5= >22.5.

For calculation of the predictors, NWP model forecast wind, temperature, height, and vertical motion forecast data from 1200Z runs at 6-hour intervals from 0 to 48 hours projection time were interpolated with a bi-cubic spline algorithm to a mesoscale grid of about 63 km spacing over southern Ontario, shown in Figure 2. The solid circles in Figure 2 are locations of the NWP model data (about 254 km resolution). Predictors known or expected to be physically related to creation of lake-effect snow were designed and calculated on the grid. Lake water temperature and mean ice cover were taken from Saulesleja (1986)

3. METHODOLOGY

3.1 Predictors

A total of 129 potential predictors were derived. Since the predictand is 24-hour snow amount, predictors were designed to cover this period. For the purpose of the explanation to follow some abbreviations are useful: the 24-hour maximum *(Mx)* minimum *(Mn)* and average *(Av)* values of a field in 24 hours (e.g. *Mn* [500 mb temperature]; sum of occurrences of some specified condition at the five 6-hour NWP model data projection times in 24 hours *(N6)*; and change from beginning to end of a 24-hour period *(C24)* of a field.

Divergence predictors include: *Av* of 1000 mb horizontal-average (H) divergence (HDIV) and 700 mb-1000 mb horizontal-vertical average divergence (VDIV) along several lines and areas over LH and GB and the surrounding land, as defined in Table 1; *N6* occurrences when the minimum divergence along the 13 J values at each I in Figure 2 lay within a line or area defined in Table 1 - summed over the I grid points in the line or area.

Table 1: I and J values in Figure 2 for horizontal averages of divergence in divergence predictors. DIV01-13 are averaged over ranges of I and J (e.g. DIV01 is calculated over the area I = 4 to 12, J = 4 to 10, DIV06 along the line I = 4 to 9, J = 8); DIV14-18 are calculated over diagonal lines (e.g. DIV14 is calculated from the points I = 4,J = 9 to I = 6,J = 8).

PRED	I	J	PRED	I	J	PRED	I	J	PRED	IJ	IJ
DIV01	4-12	4-10	DIV06	4-9	8	DIV11	9-12	4-6	DIV14	4,9	6,8
DIV02	5-7	4	DIV07	4-9	9	DIV12	9-12	7-9	DIV15	5,8	6,6
DIV03	5-7	5	DIV08	4-11	10	DIV13	4-5	9	DIV16	5,6	6,5
DIV04	4-7	6	DIV09	7-9	3-5				DIV17	7,9	8,8
DIV05	4-9	7	DIV10	7-9	6-8				DIV18	7,8	8,7

Other predictors include: *Mx, Mn, Av* of lake - 850 mb temperature differences (acronym: *Mx*[TDIF]), also *Mn* 500 mb temperature (*Mn*[T50]) near the middle of northern LH (I = 6, J = 8 in Figure 2); *Mx, Mn, N6* and *C24* of "potential for heavy snow" category (*Mx*[HVYCAT]) defined in Niziol(1987) - found by plotting lake - 850 mb temperature difference against lake - 700 mb temperature difference, calculated at (6,8); a "snow potential index" (*C24*[SNWPOT]) calculated as the sum over the 5 6-hour model data times of the product of the "potential for heavy snow" category times an arbitrary "fetch importance" index (1-3) defined locally from the 850 mb wind direction; *Av, Mn* of absolute value of 700 mb-1000 mb wind direction change, and *N6* for this wind change in the ranges 0 to < 30 degrees, and 30 to < 60 degrees over southern and northern LH (6,5 and 6,8) and central GB (8,8) (*Av*[DCH65], -68, -88, *N6*[DCH003065], -68, -88, *N6*[DCH306065], -68, -88); Av 850 mb wind direction and speed at the nearest grid point to each station (local) (*Av*[S85loc]); presence of a 500 mb low near James Bay (JBALOW); degree of cyclonic flow curvature over LH and GB, measured by *N6* of occurrences when 850 mb wind direction at (4,9) was between 280 and 340 degrees and 850 mb wind direction at (4,9) minus direction at (9,7) is at least 20 degrees (*N6*[INDTRF]), also *Av* of this difference (*Av*[D85DIFTRF]; fraction of ice cover at (6,8) over LH (ICE68) and (8,8) over GB (ICE88); *Mx* and *Av* 500 mb vorticity advection at (6,8) and (local) (*Av*[QAD5068]); *N6* for positive vorticity advection simultaneously at 500 mb, 700 mb, and 850 mb over LH at (6,8) and (local) (*N6*[PVA578loc]); *Mn* and *Av* 700mb temperature advection at (6,8) (*Mn*[TAD7068]); *Av, C24* of 850 mb wind speed and direction and 1000 mb direction over LH at (6,5) and (6,8) and GB at (8,8) (*Av*[D10068]); sum over each I = 4-12 of *N6* of the occurrences when the 700 mb wind maximum for all the 13 J's was located in one of 3 J strips: J = 2-4, 4-6, 6-8 (*N6*[W70MX46]); *Mn, Av, C24* of 700 mb vertical velocity over LH at (6,5) and (6,8) and over GB at (8,8) (*Mn*[VV7088]); *Av* of 1000 mb wind speed at (local) in twelve 30-degree segments from 360- < 30 degrees to 330- < 360 degrees (*Av*[S1003603loc], -0360loc, ... -3336loc).

3.2 CART

As previously mentioned, CART was used to select snow category classification trees for each individual station from its data base of observations and predictors. CART first finds a tree that classifies all the data perfectly, then begins "pruning" "nodes" in the "weakest links" up from the bottom of the tree until a tree structure is found which has the minimum "misclassification cost". The cost is normalized as a fraction of the misclassification cost that would occur if no tree were grown and all the data were classified by the single category which gives the lowest overall misclassification cost (usually the most common category), and can be regarded as a sort of "skill score with respect to climatology". A "ten-fold cross-validation" (CV) method was used to evaluate the cost of each tree when searching for the optimally-pruned tree. This method splits the "learning" sample (LRN) into 10 "cross-validation" (CV) sub-samples each containing 90% of LRN and with about the same distribution of categories as LRN. For each "complexity value" reached by the main tree as it is pruned, CART grows 10 auxiliary trees up to the complexity value reached by the main tree using each sub-sample, then evaluates the misclassification cost of each tree by running it down the 10% of data not contained in its tree-building sample and storing the results in a "cross-validation classification matrix". Cross-validation approximates a test of the tree with an independent data set in a conservative manner (misclassification costs are over-estimated because the full learning sample is not used to grow the trees), and is recommended for small data sets. Three construction rules for splitting the samples in the nodes were tested: GINI, TWOING, and ORDERED TWOING. GINI looks at a reduction of overall "node impurity" when searching for splits, TWOING treats each split as a two-class problem, and ORDERED TWOING is the same as TWOING except the two classes are ordered. Ordered twoing seemed appropriate for the lake-effect snow problem. Linear combinations of predictors were tried along single predictors when searching for splitting rules.

Classification trees were created for 28 stations (station 27 had only 18 LESP days) with the basic 129 predictors. For stations where only 1 or sometimes 2 observations occurred in the rarest category, that observation was classified at the next lowest category and CART was run again, if CART could not separate out the rarest category with a minimum cost tree after the first run. In most cases CART created trees at or within 1 standard deviation of the lowest possible misclassification cost which classified most or all of the observed categories at each station. For a few stations where this did not occur a "second attempt" was tried based on an idea described in Burrows(1990) for improving MDA predictand-predictor fits. Ten predictors were chosen from those that were found to classify data up to the maximum observed category in trees whose cost was too high. Squares, cubes, natural logarithms, and cross products of the 10 predictors were calculated and added to the basic predictor set then CART was re-run. This tactic was tried in an effort to take advantage of non-linear predictand-predictor relationships that might be present, and in several cases, CART found trees with substantially lower misclassifications.

4. RESULTS

4.1 Predictand

Analysis of the snowfall data for LESP days clearly showed the meso-scale nature of lake-effect snowfalls and the challenge they present to forecasters. When all 29 stations were considered together, on LESP days the highest category of snowfall observed at 1 or more stations was 1 (no snow) for .068 of the LESP days, 2 for .249, 3 for .333, 4 for .227, and 5 for .123, when LESP days were determined with Day 1 prog data. Similar figures for LESP days determined with Day 2 data were .007, .224, .358, .227, and .121, which implies little deterioration of the NWP model's forecast of the flow patterns occurred between projection times of 24 hours and 48 hours for LESP days. Figure 3a shows the fraction (decimal omitted) of the total number of data days in the 4 winters that LESP days (when classified with Day 1 prog data) were found at each station. This fraction is seen to vary with the fetch at each station, with the lowest occurrences of LESP days at the northern and southern extremities of LH. Figures 3b-f show the fraction (decimal-omitted) of LESP days when snowfall occurred in categories 1-5 at each station. The results are rather interesting. When LESP days at all stations were considered together, snow was observed by at least 1 of the 29 stations on 93% of the LESP days, yet Figure 3b shows snow *failed to occur* on roughly 1/4 to 1/2 of the LESP days at individual stations (average 36%), even in the heart of the "snowbelt" region to the lee of central Lake Huron and south-central Georgian Bay. Heavy snowfalls on LESP days at individual stations are relatively rare ... 0-9.5% for category 4 snowfalls (average 4.6%) and 0-3.7% for category 5 snowfalls (average only 1.1.%).

4.2 Classification Trees

Table 2 shows a summary of the results for Day 1 and Day 2 classification trees. Overall, the results showed considerable promise for production of both Day 1 and Day 2 guidance. In spite of the longer projection time, there was not much deterioration in accuracy between Day 1 and 2 classification trees. CART created trees that classified all the observed snowfall categories at 27 of the 29 stations for Day 1 forecasts and 20 of the 29 stations for Day 2 forecasts. For the remainder of the stations classification was to within one category of the maximum observed. As expected, the splitting rule that gave the lowest costs was for most stations was "ordered twoing". Most of the trees had normalized misclassification costs less than 1 (i.e. skill better than climatology). The cross-validated misclassification costs averaged .50 for both Day 1 and Day 2 forecasts, while the misclassification costs for the learning trees were .20 for Day 1 forecasts and .23 for Day 2 forecasts. The (CV) costs may seem high, but it should be again noted here that cross validation will *over-estimate the true cost* of using the trees with independent data because the CV trees were grown with only 90% of the data. The true costs if the trees were applied to independent data will be somewhere between CV cost and the LRN cost and hopefully, are not too far off the learning sample tree costs.

Table 2: For each station in Figure 1, maximum category forecast by "minimum cost" trees (to within 1 standard deviation); number of nodes required; cross validation (CV) misclassification costs as a fraction of cost if most frequent climatological category were always forecast (i.e. "skill" with respect to climatology); actual misclassification costs of CV and learning data (LRN) trees; node splitting rule (see page 2 of text); overall "most important" predictors (CART ad-hoc predictor "importance ranking" of 95-100). (Acronyms for predictors are explained on page 2 of the text. I,J of a grid point is appended after the acronym for some predictors which are at specific grid points e.g. *Av*[S8565] is of 24-hour average 850 mb wind speed at point I = 6,J = 5 in Figure 2). When "functions" of the same predictor appear, the number of appearances of the basic predictor is given in brackets. A star (*) between 2 predictors denotes a cross-product.

DAY 1 (0-24 hours)

STN	CATS FCST	NODES REQD	CV COST	CV MSCL COST	LRN MSCL COST	SPLIT RULE	IMPORTANT PREDICTORS
1	4	9	1.00	.55	.17	ORD	*Av*[HDIV02,HDIV16,HDIV18]
2	5	15	.88	.55	.11	TWO	*Av*[HDIV07,HDIV15]
3	3	7	1.07	.54	.14	GINI	*Av*[VDIV13,VDIV15]
4	4	13	.82	.50	.20	ORD	*Av*[S*I002427*loc]*Av*[VDIV15],*Av*[S*I002427*loc]*Av*[VDIV05]
5	5	19	.83	.55	.14	TWO	*Av*[HDIV14]**Mx*[TDIF]
6	4	9	.76	.48	.25	TWO	*Av*[HDIV13,HDIV17,HDIV07]
7	4	9	1.01	.48	.10	ORD	*Av*[HDIV08],*Av*[HDIV15]**Av*[D*I*065]
8	5	16	.93	.56	.20	ORD	*Av*[VDIV17,VDIV01,VDIV06,VDIV08,VDIV05]
9	4	15	.93	.54	.18	TWO	*Av*[HDIV06,VDIV14,VDIV10,S8565]
10	4	17	.90	.53	.17	TWO	*Av*[HDIV08]
11	5	12	1.02	.56	.25	ORD	*Av*[HDIV18,HDIV05,HDIV07,HDIV04,HDIV10,VDIV12,HDIV16, HDIV01]
12	4	7	1.03	.44	.26	TWO	*Av*[VDIV05,VDIV15]
13	3	10	.94	.41	.19	TWO	*Av*[HDIV02],*C24*[D85loc]
14	4	12	.83	.53	.28	ORD	*Av*[HDIV06,HDIV04,HDIV03]
15	4	8	.85	.52	.24	ORD	*Av*[VDIV16,VDIV12,VDIV10,HDIV09,HDIV02,VDIV01,VDIV17, VDIV04]
16	4	16	.86	.53	.20	GINI	*Av*[TDIF],*Mn*[VV7088],*Mn*[*T50*]
17	5	14	.90	.53	.26	ORD	*Av*[HDIV11]
18	4	27	.82	.51	.15	ORD	*Mx*[TDIF]**Av*[HDIV04],*Av*[TDIF]**Av*[HDIV04], *Mx*[TDIF]**N6*[DIV01]
19	5	13	.89	.55	.29	GINI	*Mn*[*T50*],*Av*[TDIF],*Mn*[TDIF],*Av*[HDIV11,HDIV09]
20	4	15	.88	.46	.19	ORD	*Mn*[*T50*]
21	4	15	.85	.42	.17	ORD	*Av*[HDIV04(3)]
22	5	16	.97	.55	.17	ORD	*Av*[TDIF],*Mn*[*T50*],*Av*[D8565]

Table 2 (cont'd):

23	4	19	1.11	.40	.12	ORD	*Av*[HDIV15,HDIV09,VDIV09,HDIV11,VDIV02,HDIV16,VDIV16, HDIV03,VDIV03,HDIV05,HDIV04,VDIV04],*Mn*[VV7088]
24	4	5	.84	.46	.34	TWO	*Av*[VDIV04]**Mn*[TDIF],*Av*[VDIV04],*Mn*[*T50*]**Av*[VDIV04]
25	3	5	1.00	.48	.23	ORD	*Av*[HDIV02]
26	3	8	.79	.46	.13	TWO	*Av*[VDIV11,HDIV11,VDIV02]
27	-	-	-	-	-	-	-
28	3	3	.87	.55	.08	GINI	*Av*[S8565,HDIV09]
29	3	4	.97	.45	.26	ORD	*Av*[VDIV15]

DAY 2 (24-48 hours)

STN	CATS FCST	NODES REQD	CV COST	CV MSCL COST	LRN MSCL COST	SPLIT RULE	IMPORTANT PREDICTORS
1	4	12	.86	.46	.09	TWO	*Av*[D*10*68],*Av*[TDIF]
2	4	12	.83	.53	.25	TWO	*Av*[S8568]
3	3	10	1.07	.44	.08	TWO	*C24*[VV7065],*Av*[TDIF]
4	4	6	.99	.63	.33	ORD	*Av*[HDIV08,HDIV13,HDIV17,VDIV17,HDIV06,VDIV18,D*10*65]
5	5	11	.92	.61	.22	ORD	*Av*[HDIV17,HDIV05]
6	4	14	.85	.54	.20	TWO	*Av*[HDIV06,VDIV14,VDIV06]
7	4	11	.99	.50	.14	GINI	*Av*[HDIV14]
8	5	12	.83	.49	.24	ORD	*Av*[VDIV17,VDIV06,HDIV05]
9	4	7	1.00	.54	.28	ORD	*Av*[HDIV06,VDIV14,HDIV10,S8565]
10	4	7	.93	.52	.33	ORD	*Av*[S8568,D8565],*Mx*[TDIF],*Mn*[TDIF]
11	5	12	1.02	.55	.21	ORD	*Av*[VDIV14]
12	4	10	.90	.39	.15	ORD	*Av*[DCH88,HDIV18,HDIV17]
13	3	7	1.03	.43	.16	GINI	*Mn*[VV7088]
14	4	12	.88	.56	.28	ORD	*Av*[VDIV15,VDIV04,HDIV16,VDIV12,HDIV18,VDIV10,HDIV03, VDIV04,VDIV18]
15	3	8	.83	.49	.28	ORD	*Av*[VDIV11,VDIV13,HDIV06],*Mx*QAD5068
16	4	21	.92	.54	.18	ORD	*C24*[D85loc],*N6*[DIV02]**Av*[TAD7068],*N6*[DIV02]**Mn*[DCH65], *Av*[D*10*65]
17	4	6	.86	.52	.34	TWO	*Av*[DIV04]**Av*[TDIF]
18	4	28	.86	.53	.15	ORD	*Av*[HDIV17,HDIV02]
19	5	21	.83	.52	.24	GINI	*Av*[TDIF],*Mx*[TDIF]
20	4	4	.91	.51	.28	TWO	*Av*[S8568]**Av*[HDIV16],*Mn*[TDIF]**Av*[HDIV16], *Mn*[TDIF]**Mn*[*T50*],*Mn*[*T50*(2)]
21	4	20	1.10	.53	.13	ORD	*Av*[HDIV03,HDIV16,HDIV05]
22	4	10	.98	.56	.34	GIN	*Av*[VDIV10,TDIF]
23	3	13	.94	.33	.14	ORD	*Av*[HDIV11(3)],*Mx*[HVYCAT]**Av*[HDIV05], *Mx*[HVYCAT]**Av*[HDIV11]
24	4	12	.97	.52	.30	ORD	*Av*[VV7088],*Mn*[*T50*],*Av*[TDIF]
25	3	5	.98	.47	.34	ORD	*Av*[HDIV16,HDIV04]
26	3	3	.93	.54	.22	TWO	*Av*[VDIV04,VDIV16,VDIV03]
27	-	-	-	-	-	-	-
28	3	6	.84	.44	.17	ORD	*Av*[VDIV02,HDIV02]
29	3	3	.83	.37	.28	GINI	*Av*[HDIV06,HDIV11]

Returning to Table 2, analysis of the most important predictors chosen by CART to make the classification trees shows that *predictors related to low-level divergence (convergence) were by far the most important at nearly every station.* The location of the line or area of this divergence was frequently upstream from or nearby to the locality of each station (e.g. HDIV02,VDIV02 for southern LH, HDIV04,VDIV04 for central LH and southern GB, HDIV17,VDIV17 for northern GB). However, low-level divergence (convergence) in the vicinity of Lake Ontario (HDIV11,VDIV11) *downstream* from stations over southern and central LH was also an important predictor. Other important predictors included measures of the degree of air-water temperature difference (e.g. TDIF, *Mn*[*T50*]), 700 mb vertical motion over the water (e.g. VV7088), measures of the low-level wind speed over the water (e.g. S8565, S8568), low-level wind direction (e.g. D*10*65,D8565,D*10*68), and degree of directional wind turning (e.g. DCH65, D85loc).

An example of typical learning sample and cross validation (CV) matrices is shown in Table 3.

Table 3: Learning sample and cross-validation classification matrices for Day 1 and 2 forecasts for station 19 (Paisley, Ontario).

OBSERVED CLASS ——»		LEARNING 1	2	3	4	5	DAY 1 CROSS VALIDATION 1	2	3	4	5
PRE-	1	60	19	4	0	0	47	36	9	0	0
DIC-	2	22	82	14	3	1	28	57	24	11	1
TED	3	2	2	31	0	1	11	12	17	10	1
	4	2	7	5	24	1	0	5	4	6	3
CLASS	5	0	0	0	0	5	0	0	0	0	3

Table 3 (cont'd):

OBSERVED CLASS ——>		LEARNING DAY 2 1	2	3	4	5	CROSS VALIDATION 1	2	3	4	5
PRE-	1	81	13	2	0	0	55	24	6	2	0
DIC-	2	11	90	12	5	0	34	56	18	10	1
TED	3	4	5	39	11	5	6	20	21	9	2
	4	0	2	10	0	0	1	6	8	5	2
CLASS	5	0	0	0	0	3	0	2	2	0	3

The fit of the data in the learning sample by CART appears to be very good, although the cross validation matrices are less impressive, but still reasonable.

The decision trees found by CART for classifying the Day 1 learning data in Table 3 are shown in figure 4. Decision rules for splitting the nodes are shown below in Table 4.

Table 4: CART decision tree rules for splitting the nodes in the Day 1 learning data for Station 19 shown in Table 3. Final classification categories are highlighted in bold. Units of some quantities are shown, divergence units are 10**-6/ sec, vorticity advection units are 10**-11 sec**-2.

Node 1: L = 2 R = 1 : split left if { -.613*Ns[DCH003065] + .553*Av[HDIV02] -.563*Mx[TDIF] } < = -12.0
Node 2: L = 2 R = 3 : split left if { -.251*Av[HDIV02] + .585Mx[TDIF] -.222*Av[S1002730loc] + .738*Ns[PVA57868] } < = 14.8
Node 3: L = 2 R = 3 : split left if *Mn*[DCH68] < = 51.3 degrees
Node 4: L = 4 R = 3 : split left if *Av*[D10068] < = 306 degrees
Node 5: L = 3 R = 4 : split left if *Mn*[T50] < = -40.7 degrees C
Node 6: L = 3 R = 5 : split left if *Av*[S1003033loc] < = 2.15 meters/sec
Node 7: L = 4 R = 3 : split left if *S1002427*loc < = 10.9 meters/sec
Node 8: L = 2 R = 3 : split left if *C24*[VV7065] < = 3.05 mb/hour
Node 9: L = 2 R = 3 : split left if *Av*[TAD7068] < = .05 degrees C/hour
Node 10: L = 1 R = 2 : split left if *Av*[TDIF] < = 20.1 degrees C
Node 11: L = 1 R = 2 : split left if *Av*[D85DIFTRF] < = 32.0 degrees
Node 12: L = 2 R = 1 : split left if *Mn*[VV7068] < = -8.15 mb/hour

The node-splitting rules above appear to be quite reasonable from a physical point of view. For example, in Node 1 heavier lake-effect snow events are split to the left into Node 2 based on the presence of low level convergence over southern LH, relatively large water-850 mb temperature difference over northern LH, and a relatively greater portion of a 24-hour period with the 700mb-1000mb wind direction change over southern LH between 0 and 30 degrees. In Node 2, events with greater low-level convergence, greater water-air temperature difference, lower local 100mb wind speed in the 270-300 degrees sector, and greater positive vorticity advection over northern LH are split to the right into Node 4. Of the 8 category 5 snowfall cases (more than 22.5 cm snow in 24 hours), 5 occurred when the 24-hour average 1000 mb wind direction at point (6,8) (middle of northern Lake Huron) was less than 306 degrees (Node 4), the 24-hour minimum 500 mb temperature was less than -40.7 degrees C (Node 5), and the 24-hour average 1000 mb wind speed in the sector 300-330 degrees was greater than 2.15 m/s (i.e. they fell into Node 6). A 6th case, with a 24-hour minimum 500 mb temperature of -39.8 degrees C, barely missed the cutoff in Node 5 and ended up classified as category 4 in Node 7. Of the 86 category 1 (no snow) cases, 65 were split to the right in Node 1 and 60 fell into Node 12 since they had less than 20.1 degrees C lake-850mb temperature difference over northern LH, less than 32 degrees cyclonic wind direction turning between Manitoulin Island and southern GB, and 700 mb vertical motion not less than -8.15 mb/hour (i.e. weak upward or sinking motion) over northern LH.

5. CONCLUSIONS

Analysis of the occurrence of snow for a four-year period at 29 stations in the lee of Lake Huron and Georgian Bay on "lake-effect snow possible" (LESP) days clearly shows the meso-scale nature of the phenomenon and that care must be taken by meteorologists when forecasting for individual stations or small areas. While snow was observed for at least 1 of the stations on 93% of the LESP days, snow failed to occur at all individual stations on roughly 1/4 to 1/2 of the LESP days (average 36%). Heavy snowfalls at individual stations were relatively rare. While category 5 snowfall (more than 22.5 cm in 24 hours) was observed somewhere in the region on 12.3% of the LESP days, at individual stations it was observed only 0-3.7% of the LESP days (average 1.1%) - the maximum number of occurrences at any station was only 8 in 4 years. "Broad brush" forecasts of snow occurrence or heavy snow amounts stand a significant chance of being wrong for individual stations, even in the heart of the "snowbelt", thus the need for careful assessment of the particulars of the synoptic situation on LESP days is clear.

The classification-tree results show the CART-based MOS method outlined here has considerable promise for production of useful objective operational meso-scale guidance for 1 and 2 day forecasts of lake-effect snow. The trees had reasonable "skill" for both 0-24 hour and 24-48 hour periods in determining the category of snow occurrence at individual stations, given that a LESP day was expected. The node-splitting rules found by CART were in most cases easily interpreted physically and are in themselves a useful tool for study as well as prediction of lake effect snow occurrence.

Low-level divergence (convergence), usually nearby or upstream and often along lines or narrow strips, was identified as the major process controlling snow amount on LESP days at nearly every station. Since divergence was computed in this study from the NWP wind forecast data interpolated to the grid in Figure 2 from a rather coarse grid of 254 km, it appears likely that in locations favoured by shore topography, low level divergence (convergence) is induced over the water by synoptic scale events occurring in the lower atmosphere above, such as cyclonic wind maxima at or below 500mb, during many lake effect snow occurrences (excluding the "land breeze" events). (As a point of speculation for events where very long snow "streamers" occur and continue far beyond the water that produced them, it may be that they form over the water (their continual moisture source) and run forward for great distances along narrow low-level convergence lines induced by a divergence region in the atmosphere above). On the opposite side, if synoptic scale features produce strong low level divergence over the water, then lake effect snow production can be limited or even curtailed. These cases have been the cause of many "bust" forecasts over the years.

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ILLUSTRATIONS

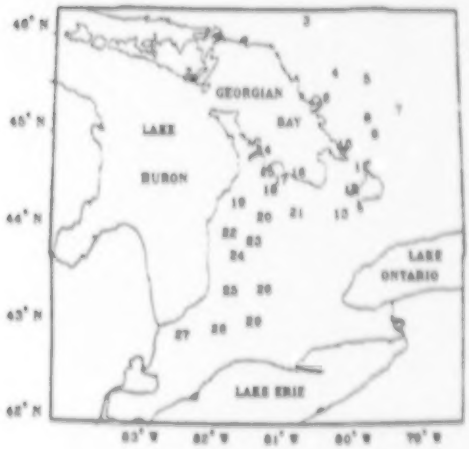

Figure 1 (above): Location of climatological stations included in this study.

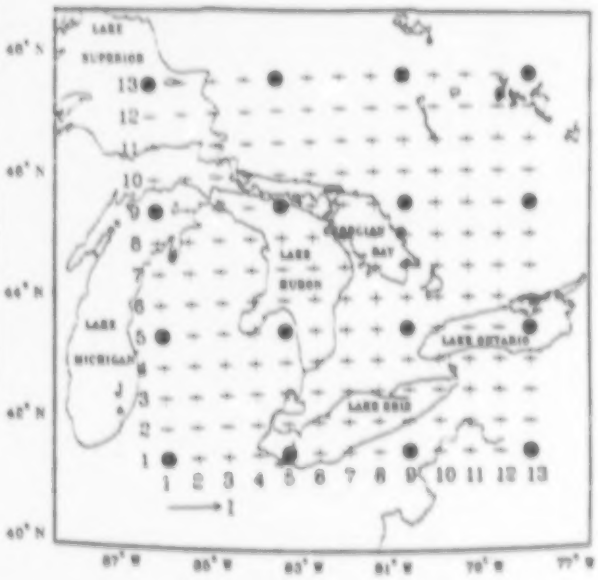

Figure 2 (right): NWP model data grid points (solid circles); interpolation grid points for calculation of predictors (plus sign).

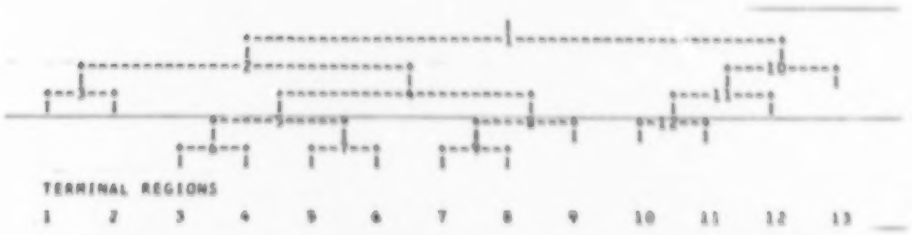

Figure 4: Snow category classification tree structure found by CART for LESP days classified with 0-24 hour (Day 1) NWP model forecast data for Station 19. Nodes are numbered 1-12, classifications for nodes and Terminal Regions are explained in text.

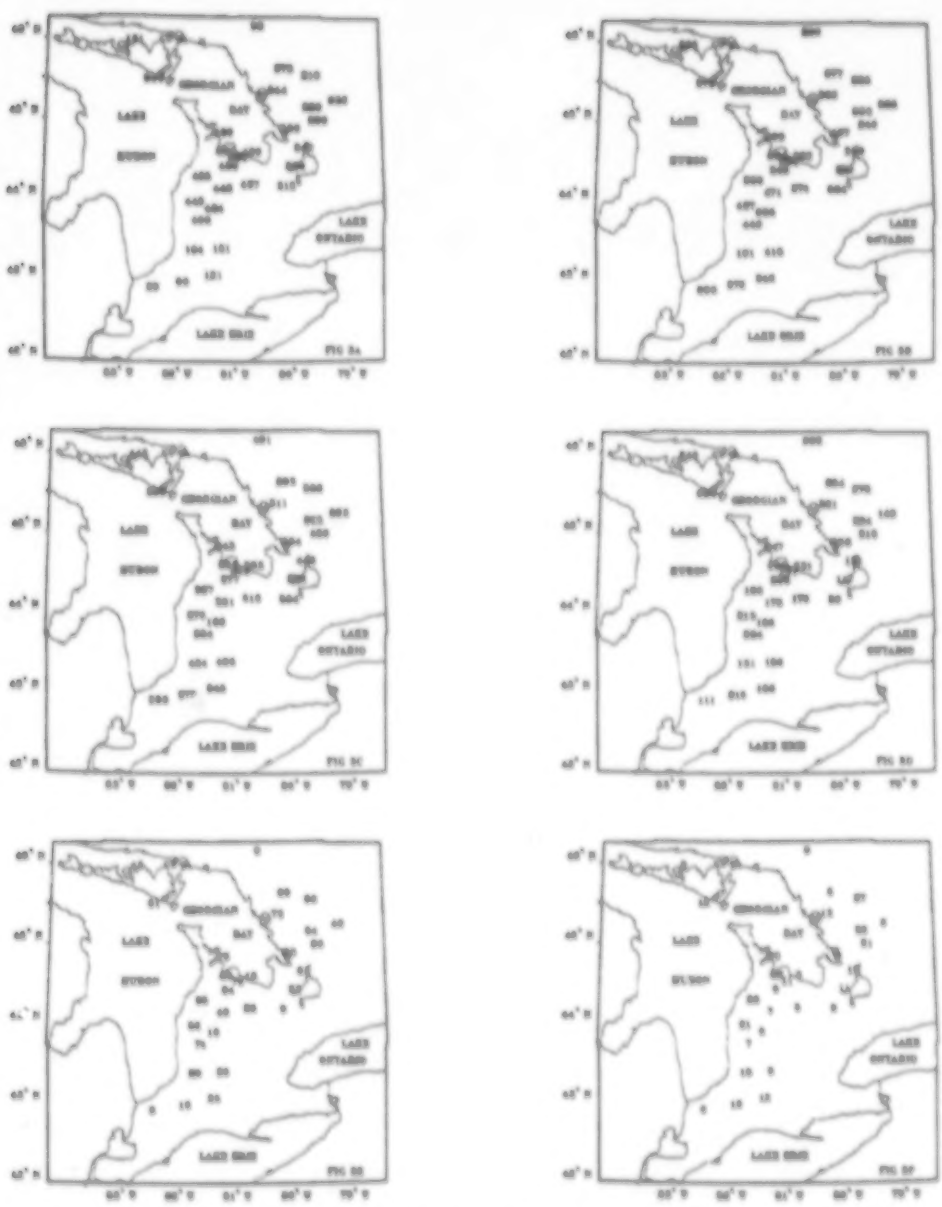

Figure 3: (a): Fraction of total days in the 4 winters studied that "lake effect snow possible" (LESP) days were identified with 0-24 hour NWP model forecast data, based on water-air temperature difference described in text and local over-water 850 mb wind direction. Decimal is omitted, e.g. 315 = .315; (b): fraction of LESP days at each station with 24-hour observed snow amount in category 1 (0 - trace). Decimal is omitted as in (a); (c): ditto for category 2 (>trace-5cm); (d): ditto for category 3 (>5-12.5 cm); (e): ditto for category 4 (>12.5-22.5 cm); (f): ditto for category 5 (>22.5 cm).

A COMPUTERIZATION OF LAKE-EFFECT SNOWFALL FORECASTS IN THE U.S.

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ABSTRACT

Efforts to forecast snow generated by cold air crossing the Great Lakes -- a mesoscale process commonly referred to as "Lake-Effect" snow -- have recently been aided by synoptic-scale computer forecast models. Using established principles of lake-effect development, key parameters such as cloud level air temperature, boundary layer wind direction and vertical velocity are selected as forecast predictors. Using a decision tree process designed by the author, each predictor value (in the form of one of the NMC computer models LFMII or NGM) is tested for application to potential lake-effect conditions over a six-hour time period. Fully qualifying situations result in quantitative snowfall forecasts, valid for designated geographical areas downwind of the appropriate lake. This technique has been highly successful and has become operational at the Cleveland, Ohio National Weather Service Forecast Office, and is being used experimentally at four other forecast offices.

RESUME

La prévision des quantités de neige associées aux grains de neige provenant des Grands Lacs est depuis peu facilitée par l'utilisation des modèles numériques de l'échelle synoptique. Se basant sur les principes reconnus de développement de cet " effet de lac ", des paramètres clefs ont été choisis comme prédicteurs comme la température au niveau du nuage, la direction du vent de couche limite et le mouvement vertical. Un arbre de décision (développé par l'auteur) permet de tester les valeurs prévues de ces prédicteurs extraites des modèles du NMC (LFMII et NGM) dans des conditions potentielles favorables d'apparition du phénomène, sur une période de 6 heures. Une situation jugée favorable amène la prévision de quantité de neige pour certaines régions en aval du lac concerné. Cette technique éprouvée est devenue opérationnelle au " Ohio National Weather Service Forecast " à Cleveland, Ohio, et est en cours d' évaluation dans quatre autres bureaux de prévision.

EXTENDED ABSTRACT

Introduction

Various techniques are used in operational lake-effect forecasting, similarly based on certain theoretically sound principles. In general, there must exist a minimum temperature difference of 13°C between the lake surface temperature and the 850mb temperature above the lake (assuming no upper-level support) along with a boundary layer fetch of at least 3 ms^{-1} wind speed over at least 155 km of open (preferably warm) water. Add to this basic concept other variables, such as the presence of upper-level synoptic scale dynamics or surface anticyclonic curvature, to account for increasing or suppressing lake-effect activity.

Selected Predictors

In this particular technique, the mesoscale event of lake-effect snow is conceived from the synoptic scale conditions -- indirectly. Operational computer models reliably forecast certain meteorological synoptic parameters which routinely account for the mesoscale occurrences of the event. For instance, approximate 850mb temperature, boundary layer wind direction/ speed, and vertical velocity are represented by Nested Grid Model Predictors (T3 + T5)/2, DD/FF, and VV, respectively. Together they indicate the specific fetch over open water (DD) with sufficient wind speed (FF) under superadiabatic conditions ($T \leq -10^{o}C$). The addition of upper-level dynamics (+VV) under conditional stability (T_{850} is 7 °C colder than the lake; generally, [(T3 + T5)/2] $\leq$ -5) allows "lake-enhanced" snow to fall at slightly higher 850mb temperatures. Maximum snowfall occurs when upper-level dynamics (+VV) combines with superadiabatic conditions ([(T3 + T5)/2] $\leq$ -10), which is referred to here as "Combination" Snowfall. The presence of anticyclonic curvature [most easily determined by comparing DD of station A to that of the nearby downwind station B; if DD_A is considered a veering wind with respect to DD_B (e.g. DD_A = 26 and DD_B = 27), then boundary layer divergence is assumed over the given region -- as is anticyclonic curvature] greatly suppresses lake-effect development, often resulting in a single thin band. Thus with just 4 model predictors, all necessary parameters for implied lake-effect snowfall can be represented.

Computer Programmed DDT

The 4 predictors are then built within the algorithm of the Dockus Decision Tree (DDT), logic based on the theoretically sound principles discussed earlier. Numerical guidance data from either NGM- or LFM-based models are inserted as the variables into the main branch of the decision tree. One Great Lakes FOUS station (e.g. CLE) is chosen to represent a finite geographical area (e.g. northeast Ohio). Figure 1 shows the achieved coverage over various parts of the Great Lakes to date (as time permits, the entire region, including Canada, will be covered by the DDT). For each area, particular boundary layer wind directions are declared as most significant fetch winds (for lack of a better term), with adjacent wind directions denoted as somewhat less significant, and so on, until the point is reached in which no fetch of any consequence exists for a selected DD. Then, a determination of typical snowfall amounts per common time period (i.e., 6-hour) is made for specific DD values within a station's area, ultimately reliant on variables of T, VV, and to some extent FF. Numerous case studies (nearly 10 years' worth) are used to best distribute the snow QPF locations, though interpolation of data

along with the author's judgements fill in the gaps until new cases can apply. Table 1 shows the "DDT-CLE" algorithm, the decision tree applied to northeast Ohio under the influence of Lake Erie fetch (there is a marked impact on northeast Ohio from a Lake Huron fetch, but that set of circumstances is covered by a separate decision tree).

Snowfall Tables

The above logic becomes the framework for a set of snowfall tables -- the final step within the computerized decision tree process. Table 2 shows a sample snowfall guide during a "standard" northeast Ohio snowfall -- that is, T < -10 with neither upper level dynamics nor anticyclonic curvature present. The keystone predictor is DD, designated as the ordinate (Y-axis) for snowfall tables. The abscissa (X-axis), meanwhile, represents slices of the geographical area, with topographical features playing a vital part. Maximum upslope areas, which normally receive higher snow amounts, are in shaded areas(EX_0, EX_1, etc.) which represent the "snow belt" sections of northeast Ohio. There are actually 15 tables which apply to northeast Ohio under various conditions, but obvious space shortages do not permit their inclusion in this extended abstract (individuals or groups wishing to receive a copy of any particular DDT algorithm may contact the author). "DDT-CLE" has been programmed by a staff meteorologist at the NWS office in Cleveland and has received operational status in November 1987. Four other NWS offices (Milwaukee, Ann Arbor, Indianapolis, and Buffalo) have their own DDT algorithm for experimental use.

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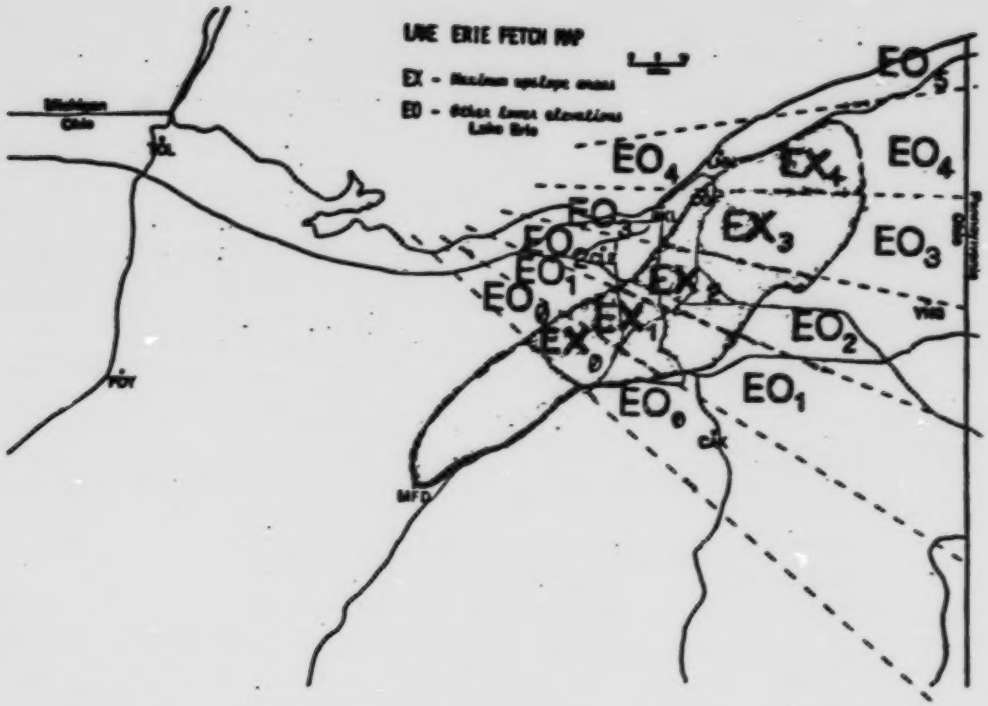

FIGURE 1. DDT Lake Erie Fetch Map – Ohio

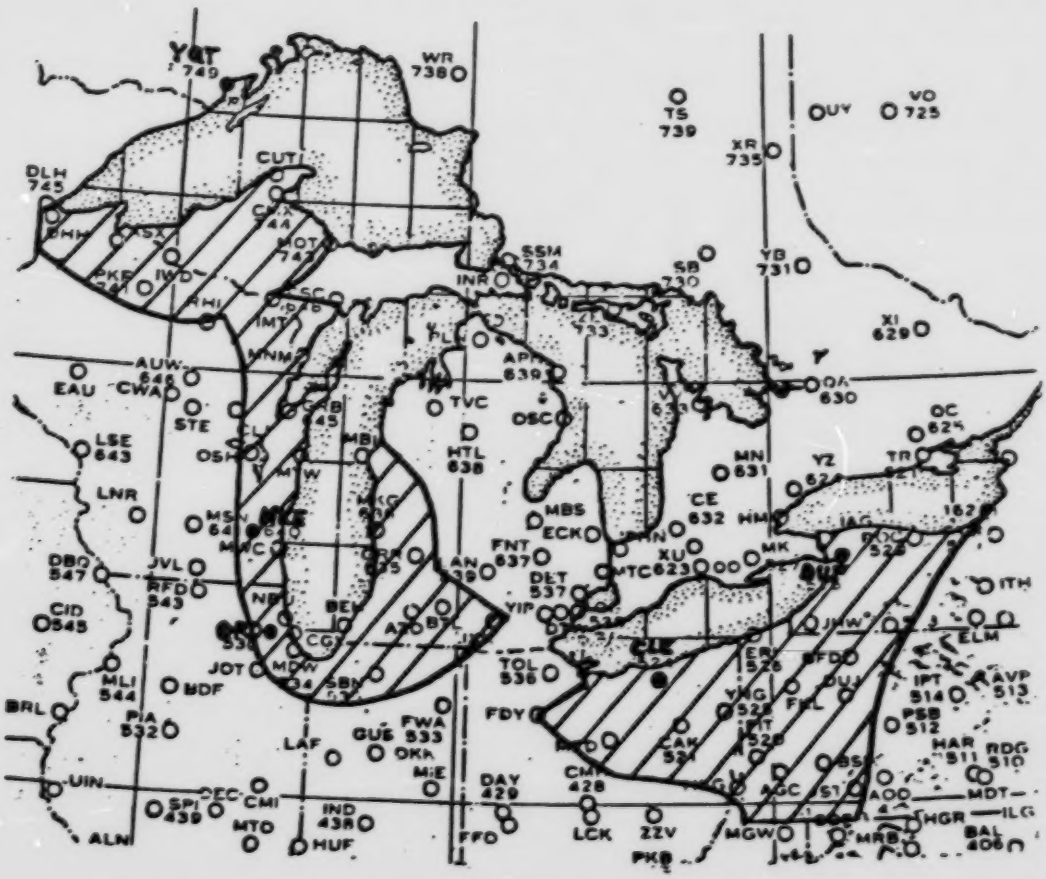

FIGURE 2. DDT Geographical Coverage (with represented FOUS stations), May 1990

TABLE 1. Dockus Decision Tree Algorithm

DDT -- DOCKUS DECISION TREE

DDT-CLE -- Lake Erie Fetch for Northeast Ohio

(X_1 = X value at beginning of sample 6-hour period, X_2 = X value at end of same 6-hour period)

T = 850mb temperature
DD = boundary wind direction in tens of degrees
FF = boundary wind speed in knots

MAIN BRANCH

STEP 1 (850mb TEMPERATURE CHECK)

a) If [{ $T_1 < -10$} AND {$T_2 < -10$}, continue to STEP 2.

b) Else if [{$T_1 \leq -10$} AND {$-9 \geq T_2 \geq -10$}] OR [{$-9 \geq T_1 \geq -10$} AND {$T_2 \leq -10$}], continue to STEP 2 but mark as Marginal*.

c) Else if [{$T_1 < -3$} AND {$-3 > T_2 > -9$}] OR [{$-3 > T_1 > -9$} AND {$T_2 < -3$}], jump to STEP 6 (ENHANCED BRANCH).

d) Else, significant Lake-Effect snow is unlikely.

STEP 2 (FETCH CHECK)

a) If [{$23 \leq DD_1 \leq 34$} AND {$23 \leq DD_2 \leq 34$}], continue to STEP 3.

b) Else if [{$DD_1 \leq 08$ OR $DD_1 \geq 27$} AND {$DD_2 \leq 08$ OR $DD_2 \geq 27$}], jump to STEP 6 (ENHANCED BRANCH).

c) Else, significant Lake-Effect snow is unlikely.

STEP 3 (DYNAMICS CHECK)

a) If {$(VV_1 + VV_2)/2 \leq 0$}, continue to STEP 4.

b) Else, jump to STEP 5.

STEP 4 (ANTICYCLONIC CHECK)

a) If [{$DD_{CLE1} \geq DD_{PIT1}$} AND {$DD_{CLE2} \geq DD_{PIT2}$} AND {$FF_1 > 10$ AND $FF_2 > 10$}], go to TABLE M if Marginal*;
else, go to TABLE E ("Standard" Table, shown in Table 2 of this extended abstract).

b) Else if {$FF_1 < 6$ OR $FF_2 < 6$}, significant Lake-Effect snow is unlikely.

c) Else, anticyclonic curvature is present, so any lake-effect snow is suppressed, probably falling in a singular "thin band"; go to TABLE E-AM if Marginal*.
else, go to TABLE E-A.

COMBINATION BRANCH

STEP 5 (STRONG DYNAMICS CHECK)

a) If [{(VV_1 + VV_2)/2 ≤ 1} OR if Marginal*)],

go to TABLE E-CM (marginal combination).

b) Else, go to TABLE E-C (combination, strong dynamics).

ENHANCED BRANCH

STEP 6 (DYNAMICS RECHECK)

a) If {(VV_1 + VV_2)/2 ≥ 0}, continue to STEP 7.

b) Else, significant Lake-Effect snow is unlikely.

STEP 7 (850mb TEMPERATURE RECHECK)

a) If {T_1 < -5 AND T_2 < -5}, continue to STEP 8.

b) Else, go to TABLE N-M (marginal enhanced).

STEP 8 (STRONG DYNAMICS CHECK)

a) If {(VV_1 + VV_2)/2 ≤ 1}, go to TABLE N (enhanced).

b) Else, go to TABLE N-D (enhanced, strong dynamics).

TABLE 2. SAMPLE LAKE-EFFECT DDT TABLE E

TABLE E: "STANDARD" TABLE – LAKE ERIE FETCH

DD1.DD2	EX0	EX0	EX1	EX1	EX2	EX2	EX3	EX3	EX4	EX4	EX6	DD1.DD2
23. 27											3	23. 27
24. 28											3	24. 28
24. 27										3	6	24. 27
24. 26											3	24. 26
25. 29								3		3	6	25. 29
25. 28								3	3	6	6	25. 28
25. 27									3	6	6	25. 27
25. 26											6	25. 26
26. 30								3		3	3	26. 30
26. 29							3	6	3	6	3	26. 29
26. 28							3	6	6	8	6	26. 28
26. 27								3	6	10	8	26. 27
26. 26										3	8	26. 26
27. 31						3		3		3		27. 31
27. 30						3	3	6	3	6	3	27. 30
27. 29						3	6	8	6	8	3	27. 29
27. 28							6	8	6	10	6	27. 28
27. 27								3	8	12	8	27. 27
28. 32						3		3				28. 32
28. 31				3		3	3	6				28. 31
28. 30				3	3	6	3	6				28. 30
28. 29					3	6	6	8	3	6		28. 29
28. 28							6	8	3	6	3	28. 28
29. 33		3		3								29. 33
29. 32		3		3		3		3				29. 32
29. 31				3	3	6		3				29. 31
29. 30				3	3	6	3	6				29. 30
29. 29					3	6	6	8		3		29. 29
30. 33		3		3								30. 33
30. 32		3		3		3						30. 32
30. 31		3	3	6	3	6		3				30. 31
30. 30			3	6	3	6	3	6				30. 30
31. 32		3		3								31. 32
31. 31	3	6	3	6								31. 31

FOR ESTIMATED SNOWFALL (INCHES) IN 6HR

AVIATION PACKAGE

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1. INTRODUCTION: The use of NWP output as guidance for the forecasting of significant weather for aviation has grown through the years.

In the U.S., Marks (1989) is experimenting with direct numerical weather prediction (NWP) model output in the forecasting an index of clear air turbulence, based on the time rate of change of the Richardson number. Keller (1989) has been experimenting with an index (SCATR) based on the rate of energy dissipation by CAT which is ultimately based on the Richardson number. Its' formulation is based on Roach's (1970) work on CAT.

Unfortunately, these authors have not compared their indices to a more established index, the Empirical index developed at the United Kingdom Meteorological Office (UKMO) by Dutton (1980). The latest implementation was reported in Forrester and Dancey (1989).

The Empirical index is proportional to the horizontal shear plus the square of the vertical shear. Dutton (1980) showed that this was superior to other common proposed turbulence indices like the Richardson number or the time rate of change of the of the Richardson number, as developed by Roach, 1970. For this reason, the Empirical index was chosen as a potential CAT predictor at the Canadian Meteorological Centre.

Another promising diagnostic tool is the Ellrod index which is proportional to the product of deformation and the vertical shear. Ellrod (1989) showed that this index is correlated to areas of turbulence. Conceptually, it is similar to the UKMO's Empirical index. For this reason it is being tested at the Canadian Meteorological centre.

The method of forecasting rime icing is a diagnostic one which uses criteria for the dewpoint depression, temperature and upward vertical motion. It is similar to the method used by the Air Force Global Weather Central (AFGWC), (Mansur, 1984). The AFGWC finds areas of potential icing at different pressure levels from their numerical model output. The AFGWC outlines those areas that exceed thresholds of temperature, humidity and vertical motion.

For convective cloud tops, the UKMO has, for the past several years, been sending out charts of the average of the level of equal areas and the equilibrium level from their global model (Forrester and Dancey, 1989). They have found that the observed convective cloud tops and those predicted by the model to be highly correlated. These convective cloud tops are calculated by using parcels lifted at the grid points of the model. The UKMO is experimenting with direct model output of convective clouds from the numerical model.

For a more complete overview of forecasting for aviation the reader is referred to Jones (1989).

2.1. Turbulence forecasting: Two indices for the forecasting of clear air turbulence are being considered: the Empirical index and the Ellrod index. The Empirical index (Dutton, 1980) is proportional to the horizontal wind shear and the square of the vertical wind shear. The Ellrod index is the vertical shear of the wind multiplied by the deformation.

The actual value of the index that is correlated with CAT may be model dependent. As the resolution of the model increases both in the vertical and the horizontal the value of the shears that is forecast in the model increases. According to the experience at the UKMO, the correlation of the indices with the occurrence of CAT must then be calibrated for each forecast model.

Interpretation: The occurrence of CAT in the areas of high values of Empirical index has been interpreted by the UKMO (Dutton, 1980) as a probability of occurrence of CAT per 100km of flight. However such a method of evaluation of the product is expensive since it requires an extensive survey of flight and much human involvement.

An interpretation of the forecasts as the point probability of the occurrence of CAT within the area would serve equally well. The forecast probability could then be correlated with a set of point observations of CAT and also correlated with the severity of the occurrence.

Method of calculation:The vertical wind shear is calculated at standard pressure levels (700,500,400,300,250, 200,150) using the finite element (RFE) model output on sigma levels. The vertical shear on a pressure level is the vertical shear between sigma levels that surround the pressure level. The vertical shear in the u-component of the wind is computed and then the vertical shear in the v-component is calculated. The wind shear is the absolute value of the two component shears.

The next step is to obtain the forecast model's component winds on standard pressure levels. The horizontal derivatives of the wind are then calculated using second order finite differences on the standard pressure levels. The wind components as well as the derivatives are rotated so that they express components in meteorological coordinates (along east and north directions).

The maximum Empirical index as well as the maximum Ellrod index is found in a vertical column over one grid point. The lowest level and the topmost level that have a value of the index greater than a threshold value are then found. The height of the levels above mean sea level is then found and plotted. This gives an indication of the vertical extent of the turbulence.

2.2 Rime icing and freezing level: The freezing level is found using model output at all sigma levels. If the RFE model surface temperature is less than zero the freezing level is set to a default negative value. Otherwise, if the surface temperature is above zero, the lowest freezing level is found through linear interpolation between layers.

Using the same model output, the areas of rime icing are found. These parameters are tested at every sigma level to see if certain criteria are met. For rime icing, the criteria for the presence of rime icing are that the temperature must lie between 0 and -16C and there must be upward vertical motion such that omega be less than -.2 Pa/s and that the dewpoint depression (T-Td) must be less than certain threshold values.

Similar criteria are used by the Air Force Global Weather Central in their automated icing forecast program (Mansur, 1984). They were based on results from an aircraft icing survey as reported in TR-80. The upward vertical motion is necessary to provide a continual source of liquid water and they used a threshold value of -1mb/hr. The value is indicative of synoptic scale vertical motion and not of locally stronger currents within the cloud structure.

The value of the omega threshold may be model dependent since higher resolution models tend to have higher omega values than those of lower resolution. Tests were made with lower criteria of omega. They seemed to overforecast the areal extent of rime icing. The value of -.2Pa/s corresponds to a value of -6mb/hr or -2ub/s, a value associated with cyclonic circulation.

The main criterion for the detection of rime icing is the so-called Appleman line (Osborne, 1975). This criterion states that there is more than a 50% probability of the occurrence of icing in stratiform clouds provided that Td>.8T and that the ambient temperature is between 0 and -12C. The AFGWC has used similar limits for the dewpoint depression. For example, with an ambient temperature between -8 and -15C, the AFGWC uses a dew point depression of 3.

In the CMC rime icing program, these aforementioned limits are all adjustable as is the Appleman criterion. The method finds the top and the bottom of the icing layer. An area of rime icing is outlined with the top and the bottom of the area indicated in thousands of feet.

The intensity of the icing is related to the rate of production of liquid water, which in turn is related to the vertical motion. Isopleths of icing intensity are identified simply as the ratio of the maximum omega in the layer containing icing and the threshold value of omega. For example if the threshold value is -.2 and the maximum value of the vertical motion is -.6Pa/s, then the icing intensity is 3.

Note:The rime icing technique will not forecast clear icing in precipitation nor will it forecast icing in convective activity. Other techniques will have to be developed to forecast these two weather elements.

2.3 Cloud forecasting: Using output from the RFE model at the sigma levels, the relative humidity and vertical motion is converted to cloud cover at all the sigma levels using the diagnostic cloud formula of Slingo (1987). The results of this cloud cover formula were compared to those through the use of the diagnostic formula presently used in the RFE (Benoit, 1987), and the diagnostic formula of Slingo (1980).

Comparison showed that the cloud cover forecast from the present RFE formula tended to increase in time and tended to overforecast the cloud. The Slingo (1980) formula also tended to overforecast cloud cover. As a result Slingo (1987) was used.

The total cloud amount is the defined as the maximum cloud amount in the column.

The ceiling or base of the cloud is height of the first level that has cloud amount of 0.6. If first level encountered has a cloud amount greater than .6, the level at which the cloud amount is equal to .6 is found by interpolating linearly downward. This height is above MSL.

The cloud top is defined as the first level (from the top of the column) that has an amount equal to .6. Again as in the ceiling height, the level where the amount is equal to .6 is found by interpolating linearly upward. This height is above MSL.

The Slingo (1987) formula is valid only for stratiform cloud. The ceiling is further adjusted in the case where there is some instability. This is defined in the cases where the heat flux from the surface is greater than 50 watts/m^2 (this criterion may be adjusted in the future). The height of the ceiling is set to 4.95 times the surface dewpoint depression.

2.4 Buoyant energy: The level of equal areas (the maximum cloud top) and the equilibrium level can be used for convective cloud forecasting. Since the cloud forecasting technique in the previous section will not forecast convective cloud, this technique should be used for that purpose.

The total wind shear is calculated using the U and V components of the wind below the level sigma=.85. This will approximate the average wind shear below 6000 feet.

The parcel is lifted from the level containing the highest thetaw in the lowest 200mb above the surface. It is lifted (adiabatically to the lifting condensation level and moist adiabatically afterwards) to the level of free convection (if it exists), and hence to the equilibrium level and the level of equal areas. This parcel lift is done without entrainment. The buoyant energy is the positive energy between below the equilibrium level.

The height above mean sea level of the equilibrium level and the level of equal areas (maximum tops) is found by linearly interpolating the geopotential height to the pressure levels at which they were found. Then a sampling subroutine finds the maximum levels in a cluster of points and finds the location of the maximum.

The range of TCU/CB tops may be expressed at the average of the maximum tops or the equilibrium level. The intensity of the convective activity is measured by the buoyant energy.

In addition to the importance of the low level shear to convective activity, the low level wind shear may be important in its own right. Areas of strong low level wind shear are important for aircraft especially on take-off and landing.

2.5 Mean sea level forecast: This chart contains the mean sea level pressure in isobars as well as the model surface wind speed. In addition, there is an indicator of low level turbulence. The surface stress of the NWP is contoured intervals of .75 1.5 and 3 Pa. These levels should correspond to levels of moderate, severe and extreme mechanical turbulence in the low levels.

The surface stress of the model will increase as the vertical wind shear increases, the surface roughness and the instability increases. The surface stress will decrease if the converses is true.

The height of the top of the mechanical turbulence area is a fraction of the height of the planetary boundary layer. The planetary boundary layer height under stable conditions is found. It is compared to PBL height of the model which is valid in unstable conditions. The maximum of the two is chosen.

3. Conclusions: The use of guidance charts for forecasting of significant weather for aviation, can only be determined through detailed evaluation of the charts.

Presently the Newfoundland Weather Centre, is evaluating the aviation package. The centre will determine which of the two indices is better, what values of the index seem to be correlated with CAT, and will perform objective and subjective evaluations of the different products in the aviation package.

Based on their evaluations, CMC will issue a series of aviation charts to all the regions.

Work is under way to incorporate liquid water content as prognostic variable within the RFE. This could be used to forecast clouds and icing directly from model output.

A opposed to a diagnostic method of forecasting convection, the direct model output of the Kuo convection method could be used to forecast convective cloud cover, the bases and tops of convection and the intensity of convective precipitation.

The UKMO is currently looking at these methods for the forecasting of clouds icing and convection (Forrester and Dancey, 1989).

The turbulent indices will not forecast mountain waves. There is code in the model that detects gravity waves generated in the model. The output of the gravity wave drag module could be investigated as a possible predictor for mountain waves.

Finally, the RFE forecasts turbulent energy directly at all sigma levels. This variable could be used to forecast zones of low level mechanical turbulence as well as areas of clear air turbulence.

This parameter will be investigated in the future as to its suitability for turbulence forecasting for aviation.

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VERIFICATION OF EXPERIMENTAL AVIATION PACKAGE 1989/90

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Abstract

In summer 1989, the Canadian Meteorological Centre began transmitting an experimental aviation weather package based on the Regional Finite Element model. Parameters forecast include turbulence, icing and other aviation related pamameters. The Newfoundland Weather Centre is verifing this package for eastern Canada and the North Atlantic. Preliminary results indicate that the package has potential for forecasting elements such as icing and turbulence. It appears that the forecasting of some parameters can be achieved through the use of numerical models and can lead to a better service to the aviation industry.

A l'été 1989, le Centre Météorologique Canadien a débuté l'émission d'une série experimentale de cartes destinée à l'aviation. Parmi les paramètres prévus figurent; la turbulence , le givrage ainsi que d'autres éléments reliés a l'aviation. Le Centre Météorologique de Terre-Neuve s'est vue attribué la vérification de ce produit pour l'est du Canada et l'océan Atlantique. Les résultats préliminaires indique que ce produit a un potentiel pour la prévision de certains éléments météorologiques. Ceci démontre que la prévision de certains paramètres peut être réalisée adéquatement par un modèle numérique et peut mener à un meilleur service pour l'aviation.

1. Introduction

In August, 1989 the Newfoundland Weather Centre (N.W.C.) was assigned to verify the EXPERIMENTAL AVIATION PACKAGE for eastern Canada and the western North Atlantic. This package is produced twice daily by the Canadian Meterological Centre (CMC) and is based on the Regional Finite Element Model (RFE). Several aviation related meteorological parameters such as mechanical turbulence, rime icing, wind shear, buoyant energy and two indices of clear air turbulence are depicted by the package and are forecast for T+6, T+12, T+18 and T+24 hours.

Since the verification process is not yet complete, the results presented here are very preliminary and will be subject to modification by the time the study is completed by the summer of 1990.

This paper will examine briefly the methodology of the verification process and give a preliminary evaluation of the package as a useful predictor of the meterological parameters that impact on inflight aircraft.

2. Methodology

2.1. The Mean Sea Level Chart

The mean sea level chart utilizes solid lines to represent the isobaric pressure field. Dashed lines are used to contour the surface wind at increments of 10 knots. Thick solid lines contour the surface stress in Pascal units. Small numbers within the surface stress field represent the forecast top of mechanical turbulence in thousands of feet.

The pressure field was verified objectively using the NWC surface analysis. If the predicted central pressure values of highs and lows differed from the analyzed values by more than 6 mb, verification of the remaining parameters was not completed since they are directly related to the pressure gradient. When the pressure field was verified with the analysis, the surface wind was considered to be verified.

The verification process utilized pattern recognition. Isotachs are traced on the NWC surface pressure analysis and then compared to the isotach pattern generated by the model. After a few months of comparison, it seemed that the wind forecast was on average 5 knots too light. In a follow-up study yet to be completed, a comparison will be done between the forecast and observed winds in different synoptic situations such as in warm sectors, behind cold fronts, ahead of systems and in a straight flow.

Mechanical turbulence below 10,000 ft was verified using the location of aircraft reports of turbulence versus the location of forecast surface stress. About 145 reports were collected from November, 1989 to February, 1990. A hit was considered every time the location of a report of light to moderate turbulence or greater corresponded to a surface stress contour of at least 0.50 Pa. Figure 1 indicates 80% of the aircraft reports verified and about 18% were misses events. Near miss events constituted about 2% of the population and were considered to have occurred when a contour was within about 160 km of the location where turbulence was reported.

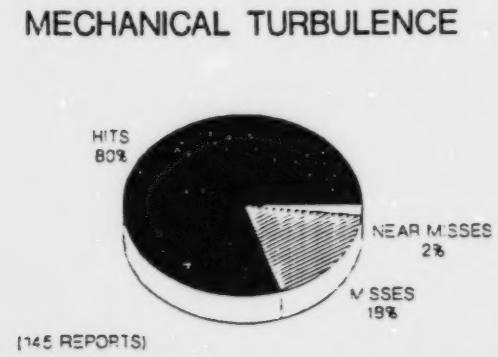

FIG. 1

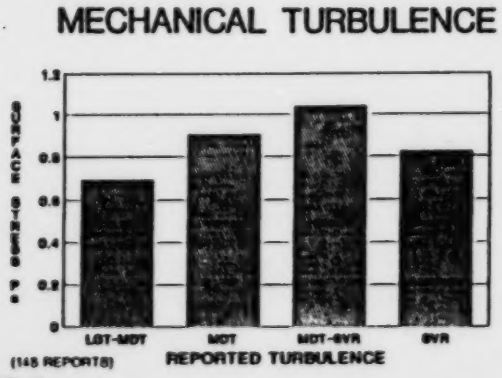

FIG. 2

Figure 2 shows how surface stress is related to the severity of mechanical turbulence. As expected, the more severe the turbulence, the greater the surface stress depicted for the same location. The correspondence of slightly lower surface stress values to severe turbulence reports was attributed to the small number of reported cases. The model may be more capable of predicting severe turbulence events if the topography in the numerical model was more detailed.

So far, verification of the tops of the turbulent layer predicted by the model has not been completed.

In conclusion, there seems to be a significant relationship between the predicted location of surface stress values equal or greater than 0.75 Pa and the location of reported cases of moderate mechanical turbulence or greater.

2.2. Cloud Cover Chart

The cloud cover chart depicts the distribution and vertical extent of low and middle cloud. Different grey tones are used to distinguish between the two cloud types. Within the cloud areas are numbers that indicate the base of the first broken layer and the top of the highest layer. This cloud depiction represents system cloud and therefore do not account for circulation weather cloudiness.

The evaluation of the horizontal and vertical extent of the predicted cloud utilized satellite pictures and tephigram analyses from selected sites in eastern Canada, Greenland, Iceland and ship locations. The model seemed to represent the horizontal extent of cloudiness quite well. It was difficult to evaluate the predicted bases of low cloud over the ocean since very few soundings were available for comparison.

2.3. Freezing Level and Rime Icing Chart

This chart uses thick solid lines to represent freezing levels at a variety of prescribed heights and dashed lines to depict the location and relative intensity of rime icing. The icing contours give a direct measure of the severity of icing. The freezing level predictions were verified using the available soundings. It was found that the freezing level usually verified to within one or two thousand feet of the actual levels taken from the soundings.

The icing forecast was evaluated using pilot reports. Up to the beginning of February, 1990, 53 reports were collected. The icing forecast is highly dependant on the model's ability

to forecast cloud cover. Boundary layer circulation type cloudiness is not handled well by the model. Since a significant number of rime icing reports occurred at low altitudes during departure and approach through circulation type cloud the model tended to underpredict such events as shown by figure 3. However, the model tended to perform well ahead of warm fronts where system cloud is more common. Figure 4 shows the model performance in a variety of synoptic situations. Performance was poor in westerly flows across Newfoundland, particularly over western Newfoundland where onshore winds and upslope flow contribute to circulation cloudiness.

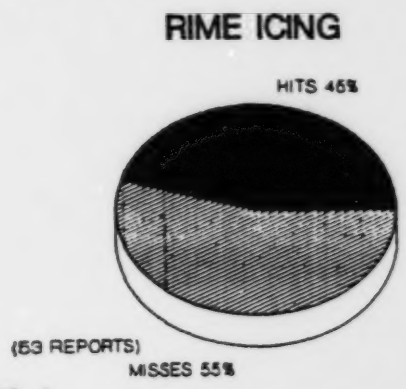

FIG. 3

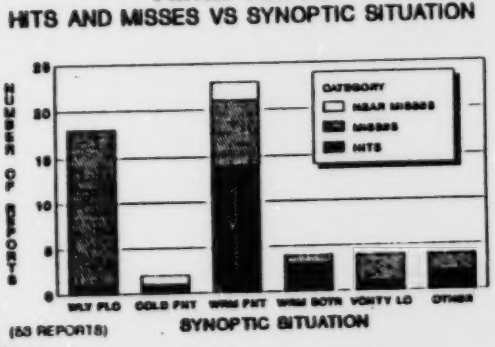

FIG. 4

2.4. Buoyant Energy and Wind Shear Chart

Solid lines represent buoyant energy contours expressed in J/kg/100 and dashed lines represent wind shear in kt/1000 ft. At this stage, not much work has been completed using this chart. Eventually the predicted wind shear will be compared with the shear indicated by the available soundings. It is not yet clear how the best verify the buoyant energy forecast.

2.5. Clear air turbulence Chart

Two indices of clear air turbulence, Ellrod and Empirical, are depicted on separate charts in an experimental package. The Empirical index is contoured at increments of 10 with a starting value of 10. The Ellrod index is contoured at increments of 30 with a starting value of 30. The two indices are quite similar as they both increase as the vertical or horizontal shear increases.

Pilot reports over the Atlantic ocean were used to evaluate the predicted turbulence indices. Aircraft going across the Atlantic have to report at every ten degrees of longitude along their routes which most of the time are oriented in an east-west direction. When an aircraft reported turbulence at or between mandatory reporting points, the magnitude of the turbulence was compared with the largest model generated index (both Empirical and Ellrod) over the 10 degrees ending at the reporting point. What was evaluated was more or less a band of turbulence about 95 km wide and 10 degrees of longitude in length (about 500 km). A 500 km long line on the clear air turbulence charts very likely crossed more than one contour. The highest valued contour in the sector was chosen to correlate with the reported turbulence in the same sector because the PIREP always indicated the strongest turbulence experienced by the aircraft in that sector. So far, not much consideration has been given to evaluating the predicted depths of the turbulent layers. However, verification methods will utilize the 3 sigma layers corresponding to altitudes between 29 and 40 thousand feet most frequently utilized by trans Atlantic aircraft.

Preliminary results indicate that both indices appear to verify well although the Ellrod index seems to be slightly better at predicting the extent and magnitude of clear air turbulence.

A report of light to moderate turbulence or greater was considered a hit event if there was at least one index contour within the 10 degrees of longitude ending at the plane's reporting position. Missed events occurred when there was no contour index along the 10 degrees of longitude track. Reports that were incomplete or reports of turbulence associated with gravity waves, especially off Greenland were rejected. Figure 5 shows that the Ellrod index verified slightly better than the Empirical index in terms of its greater number of prediction successes and fewer missed events. Figure 6 reveals the magnitude of the Empirical index at a particular location is directly proportional to the magnitude of reported turbulence at that point.

It is noted though that the contour increment is 10. Therefore the difference between light to moderate and moderate turbulence is not significant but as it gets to moderate to severe and greater turbulence the difference is significant. The same information can be formulated for the Ellrod index shown on fig. 7. The difference is even greater for the Ellrod index in that there are more than 2 contours difference between the moderate and moderate to severe turbulence.

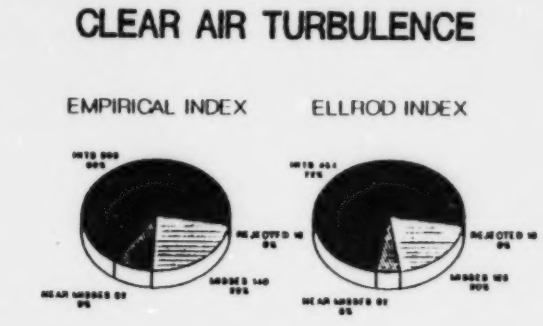

FIG. 6

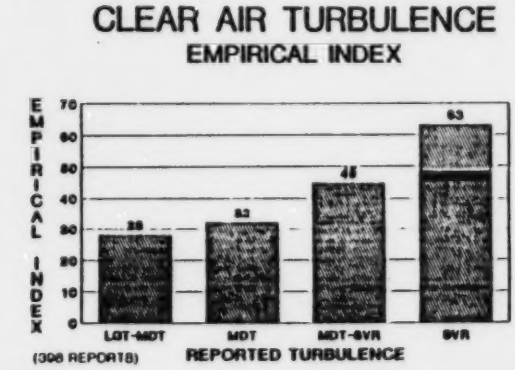

FIG. 6

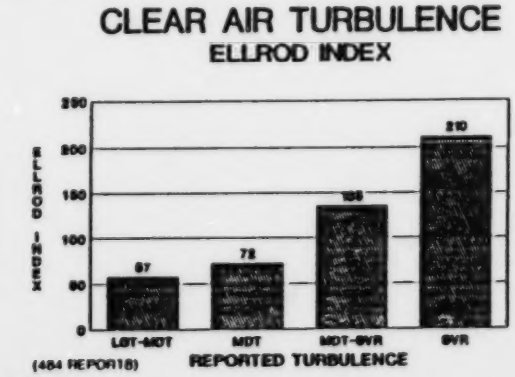

FIG. 7

Early results also indicate that the severity of reported turbulence is very dependant on aircraft type and flight level.

There were very few reported cases of moderate to severe or severe turbulence to evaluate against areas of predicted turbulence of similar intensities because air traffic is usually diverted around such areas when SIGMETS for such activities are issued.

A number of cases studies are in progress to evaluate particular clear air turbulence events and to evaluate the false alarm potential of the models in over predicting such events.

3. Conclusions

The Experimental Aviation Package was developed with the aim to improve the prediction of several significant meteorological parameters affecting aircraft at both high and low altitudes. An evaluation of the package's performance in predicting the scale in both time and extent of the parameters is continuing at the Newfoundland Weather Centre.

Early results suggest that the RFE model shows the potential for considerable skill in forecasting elements such as rime icing and turbulence. A few weaknesses have been identified in the course of the evaluation process and a final report later in the year should be more definitive about particular strengths and weaknesses in the package. However, it appears worthwhile improvement in the forecasts of turbulence and icing can be achieved through the use of numerical models and can lead to improve flight planning strategies to minimize the impact of significant icing and turbulence events inflight aircraft.

USE OF SPECIALIZED METEOROLOGICAL PRODUCTS FOR ICE ANALYSIS AND FORECASTING

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ABSTRACT/RESUME

Environment Canada Ice Centre produces ice analysis charts and forecasts for eastern and northern Canadian waters as well as for the Great Lakes. These products are generated by integrating information from reconnaissance flights; NOAA, Spot and Landsat satellite images; ship and shore reports; oceanographic and meteorological parameters; and passive microwave data. However, the Ice Centre " nowcast" approach required the development of specialized meteorological products to incorporate into the daily ice analyses and forecasts. This poster session will display some of these products and give brief explanations as to how they are used in Ice Centre.

Le Centre des glaces d'Environnement Canada fournit des prévisions et des cartes d'analyse des glaces sur les eaux nord et est du Canada, ainsi que sur les Grands Lacs. Ces produits proviennent des données recueillies lors des vols de reconnaissance; des images satellitaires de NOAA, Spot et Landsat; des rapports rédigés à bord des navires et dans les bases côtières; des paramètres océanographiques et météorologiques; et des données passives recueillies par micro-ondes. Toutefois, l'approche préconisée par le Centre des Glaces, qui consiste à faire des observations plutôt que des prévisions, a nécessité la création de produits météorologiques spécialisés, à incorporer aux prévisions et aux analyses quotidiennes des conditions glacielles. Lors de cette réunion informelle, nous vous montrerons quelques-uns de ces produits et nous vous en expliquerons brièvement l'utilisation par le Centre des glaces.

MEAN 1000 MB CHARTS

Mean 1000 mb charts are used as a tool by meteorologists at Ice Centre in the production of every analysis and forecast. The charts provide an indication of wind flow over the area for specified time periods, thereby allowing meteorologists to estimate the amount of ice drift attributable to wind. It has been found that the ice tends to drift roughly parallel to the 1000 mb contours. The strength of the mean surface wind determines the rate of wind induced ice drift. Generally, about 2 percent of the surface wind speed is used to determine the speed of ice motion. Following these general guidelines for free drifting ice the forecaster uses the 1000 mb contour chart as an aid to forecast the velocity of ice motion. Areas where ice pressure may develop or open water leads may form can also be implied from the 1000 mb contour charts. The strength of the wind would determine the severity of the pressure or how quickly an open water lead could be

expected to form. To meet Ice Centre's unique requirements special programs run at the Canadian Meteorological Centre in order to provide mean 1000 mb charts for specific time periods which are outlined in the following subsections.

Four Panel Mean 1000 mb Chart

The four panel mean 1000 mb chart displays contours for four different time periods. There is one panel that is for an 18 hour mean from yesterday at 1800 UTC to today at 1200 UTC. This panel is used as an indication of the type of ice motion that would have occurred from the ice analysis time yesterday to about the time of issue for most Ice Centre forecasts today. Another panel indicates a 12 hour mean from 1200 UTC today to 2400 UTC today. This is used to estimate ice motion from forecast issue time through the remainder of today. The last two panels are 24 hour means starting and ending at 0000 UTC for tomorrow and the next day. These are used as tools for estimating ice drift for the forecast and outlook portion of Ice Centre bulletins which are issued daily.

24 Hour Forecast Mean 1000 mb Chart

This chart, displayed in figure 1, is a 24 hour mean valid at 1800 UTC daily and is used as an indication of ice motion from analysis time yesterday to analysis time today.

24 Hour Mean 1000 mb Analysis Chart

This chart is an analysis of the 24 hour mean 1000 mb flow valid for the same time period as the 24 hour forecast chart mentioned above. It is used for verification purposes and also in the production of various analyses and forecasts.

Weekly Mean 1000 mb Chart

Composite charts of general ice conditions in the Canadian Arctic are produced on a regular weekly basis. This chart gives an indication of the mean flow over the area since the last composite was produced.

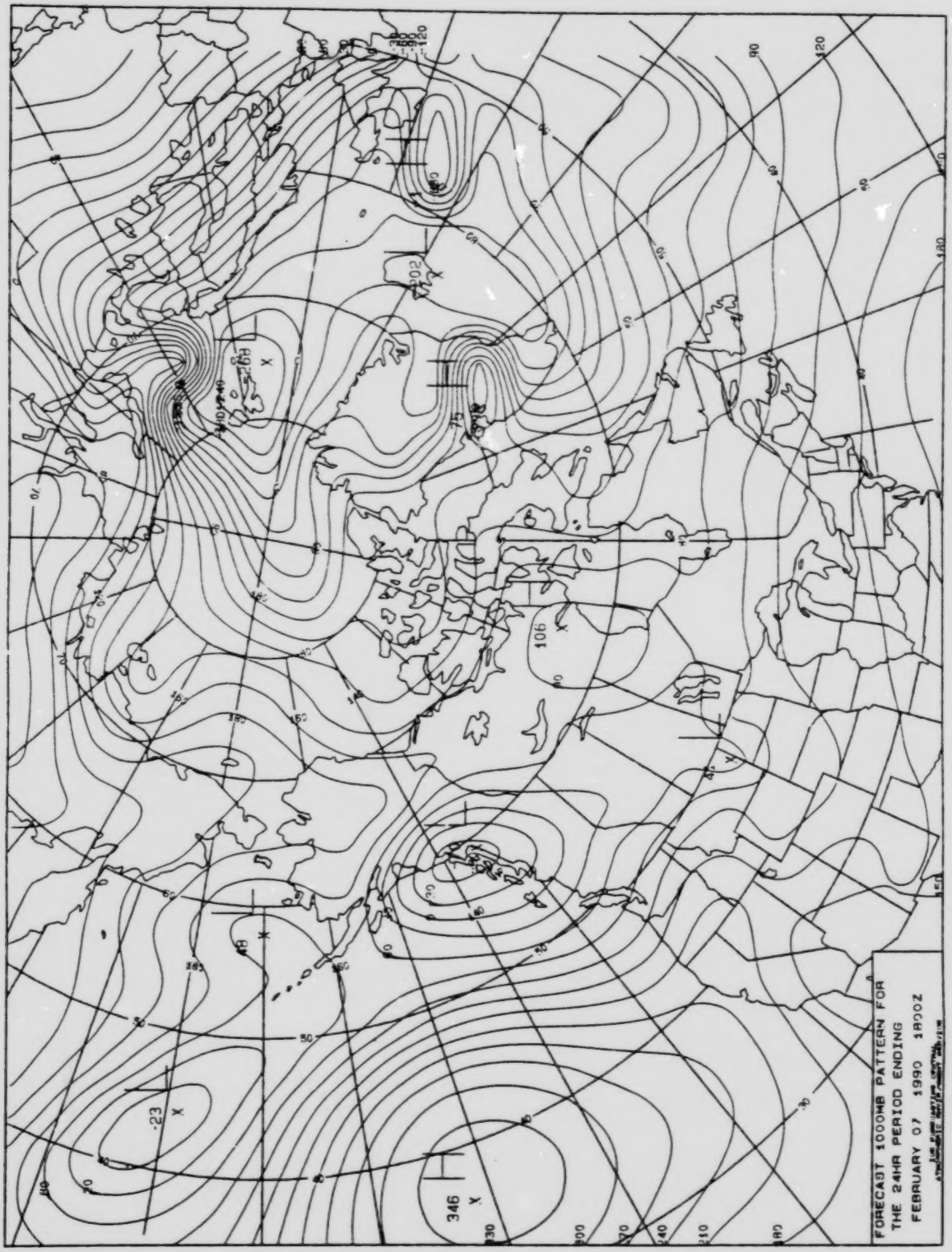
Monthly Mean 1000 mb Chart

This chart is used during the production of long range forecasts which normally include a short summary of past conditions. The monthly mean 1000 mb chart can be compared to monthly normals to give an indication of reasons why the ice conditions are better or worse than normal.

FREEZING DEGREE DAY ACCUMULATIONS

Freezing degree day accumulations are used at Ice Centre for a number of reasons. First of all, they can give a good indication of the severity of ice conditions. If the freezing degree day accumulation is greater than normal at a given location, then the

Figure 1 - 24 hour Forecast 1000mb Pattern



ice conditions are usually worse than normal for that time of year. Secondly, freezing degree day accumulations can be used to estimate the thickness of ice over a given area. Zubov developed a correlation between freezing degree day accumulations and ice thickness which has been incorporated in a computer program at Ice Centre. Lastly, a forecast of freezing degree day accumulations can be used as a tool to estimate when the first ice will likely appear at a site or to find an analogue year for producing long range ice forecasts. Figure 2 shows an example of the output of program "NMSUM" at Ice Centre which gives a value for freezing degree days over a specified time period, (Acc), the total freezing degree days at this point in the ice season, (Fdd), and the thickness of ice as estimated using the formula developed by Zubov, (Tks).

Figure 2 - Output from program "NMSUM"

```
++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
                    Climatological Summary for YSU

Stn Mnth Yr    Acc Dd       Tks  Drift          MeanT Dev      Fdd Mdd

YSU Jan 1990*(-158  4) * ( 44 265/00080) * (-6.2  0.6) * ( -572 0)
++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
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TEMPERATURE VS. TIME GRAPHS

Temperature vs. time graphs are plotted regularly at Ice Centre, (see figure 3). The plot consists of a smooth line, which indicates the smoothed normal daily mean temperatures at the site, and an irregular line which indicates the actual mean daily temperatures for the site. This is used as a quick reference in long range forecasting to supplement the freezing degree day accumulations. A number of past years may have had similar freezing degree day totals but the temperature vs. time graphs provide insight into the short term temperature trends during the years in question. This enables the forecaster to narrow down the choices when trying to find an analogue year for seasonal and thirty day forecasts.

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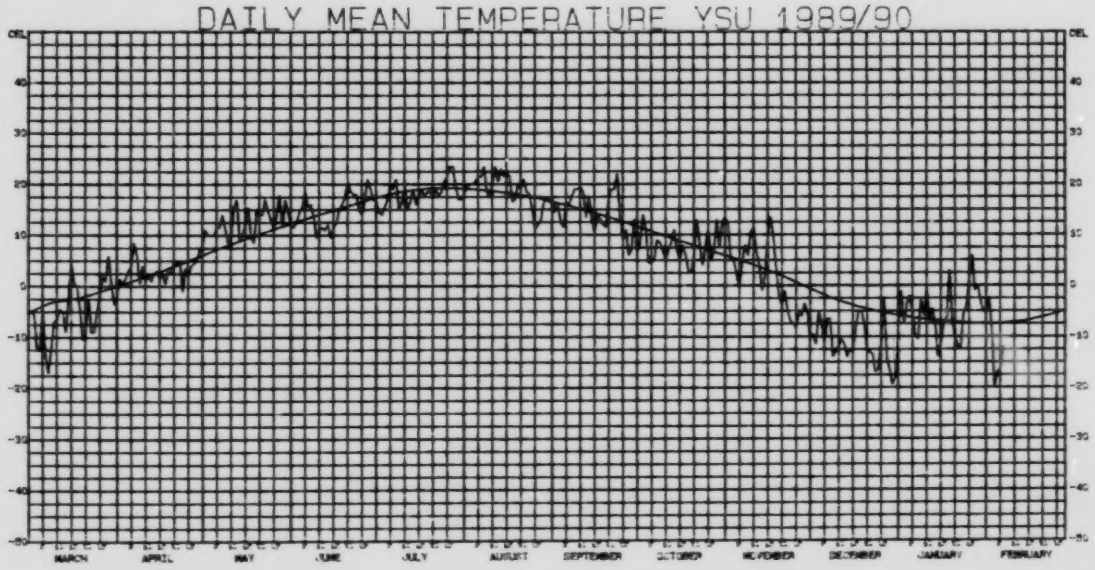
Figure 3 - Temperature Vs. Time Graph for Summerside



PREDICTING THE SKILL OF EXTENDED-RANGE FORECASTS

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ABSTRACT

A method is proposed to discriminate between skillful and unskillful forecasts of 30-day averaged 500-mb height anomalies using the initial conditions from which the forecasts were generated as the discriminator. The method was developed from an examination to thirty 30-day forecasts (run from the first of each month during ten recent winter seasons) by the Community Climate Model (CCM) at the National Center for Atmospheric Research (NCAR). Specifically, initial conditions in which there are faster than normal geostrophic westerlies at 500 mb over the western Atlantic Ocean and weaker than normal westerlies over Europe are more likely to be followed by unskillful forecasts of 30-day 500 mb height anomalies than are opposite initial conditions, i.e. weaker than normal westerlies over the western Atlantic and faster than normal westerlies over Europe. The method appears to work as well for the experimental 30-day forecasts by the National Meteorological Center (NMC). It is hypothesized that 30-day forecast skill is determined by medium-range cyclone forecast skill which in turn depends upon the initial conditions.

RÉSUMÉ

Nous proposons une façon de discriminer entre bonnes et mauvaises prévisions de la moyenne de 30 jours des anomalies de hauteur de la 500 mb en se servant des conditions initiales menant aux prévions comme facteur discrimant. La méthode fut développée avec un échantillon de 30 prévisions de 30 jours (faites le premier de chaque mois d'hiver pour les 10 derniers hivers) obtenues avec le "Community Climate Model" (CCM) du "National Center for Atmospheric Research" (NCAR). En fait, des conditions initiales telles que des vents géostrophiques à 500 mb plus forts que la normale sur la partie ouest de l'Atlantique et plus faibles que la normale sur l'Europe, amènent une plus grande probabilité d'une mauvaise prévision de l'anomalie de hauteur moyenne de 30 jours de la 500 mb que des conditions initiales contraires i.e. des vents d'ouest plus forts que la normale sur l'Europe et plus faibles que la normale sur l'ouest de l'Atlantique. La méthode semble fonctionnée aussi pour les prévisions de 30 jours du "National Weather Center" (NMC). Nous croyons que l'aptitude à prévoir de la prévision de 30 jours est déterminée par la prévision à moyen terme des dépressions qui en retour dépendent des conditions initiales.

INTRODUCTION

Extended-range forecasts are defined to be predictions of weather elements beyond ten days in advance of the initial time. In operational practice, these are usually presented as forecasts of surface temperature and precipitation anomalies (departures from normal) averaged over a thirty period ending a month in advance of the initial time (i.e. 30-day outlooks). Preisendorfer and Mobley (1984) have shown that the official 30-day outlooks issued by the National Weather Service in the United States are no more accurate (relative to chance) than forecasts of persistence and are thus marginally skillful.

These outlooks are subjectively prepared based upon available guidance which, at present, does not include output of numerical forecast models integrated out to 30 days in advance. However, experimental 30-day integrations of the NMC global spectral model (Sela, 1980) were run for a selected period at NMC and are described by Tracton et al. (1989). Experimental 30-day forecasts have also been run from observed initial conditions by the NCAR CCM. The experimental NCAR and NMC 30-day forecasts are predictions of 500 mb height anomalies averaged over the period 30 days in advance of initial time. The accuracy of each forecast is measured with an anomaly correlation (AC) defined by

$$AC = \frac{\overline{(Z_O - Z_C)(Z_F - Z_C)}}{\sqrt{\overline{(Z_O - Z_C)^2}\,\overline{(Z_F - Z_C)^2}}},$$

where Z_F, Z_O and Z_C are respectively the forecast, observed and climatological 500 mb height at a grid point and the overbar denotes a domain average. Forecasts which are skillful relative to climatology have AC in excess of 0.5 (Murphy and Epstein, 1989). The average AC of the NMC 30-day forecasts is an unskillful 0.40, but some of the forecasts are skillful (Tracton et al. 1989, Fig. 5a). Similar results were found in the NCAR experiments. It is thus clear from these experiments that resulting 30-day forecast skill is quite variable from one initial time to the next. The question raised by these experiments is whether there is information in the initial fields from which the forecasts are generated which can be used to anticipate the skill of the forecasts. If so, then a forecaster could potentially know when and when not to use 30-day model integrations as guidance in the preparation of 30-day outlooks. This report addresses this question using the NCAR forecasts as data.

METHODS AND RESULTS

A sample of thirty 30-day forecasts by the NCAR CCM, run from initial conditions on the first day of each winter month (December, January, and February) during ten recent winter seasons (1978-79 through 1987-88) were examined in this study. The average AC of these forecasts was an unskillful 0.36. The initial 500 mb height fields of the five best forecasts in this sample (with average AC = 0.64) and five worst forecasts (with average AC = 0.02) are composited together in Fig. 1 and 2, respectively. Among other differences, attention is drawn to the apparent split in the 500 mb geostrophic flow over the

western Atlantic in Fig. 1 but over Europe in Fig. 2. The 500 mb geostrophic westerly wind at 50°N (proportional to the height at 40°N minus that at 60°N) is greater at 10°E than at 50°W in Fig. 1, but greater at 50°W than at 10°E in Fig. 2. The geostrophic westerly wind calculated this way is actually a form of the zonal index (Rossby and collaborators, 1939). Expressed as departures from normal, the zonal index is below normal at 50°W and above normal at 10°E in Fig. 1, but above normal at 50°W and below normal at 10°E in Fig. 2.

Defining initial weather regime by the signs of the zonal index anomalies at 50°W and 10°E, each initial 500 mb height field in the sample can be assigned to one of four possible regimes: (1) below normal index at 50°W and above normal at 10°E (-+); (2) above normal index at 50°W and below normal at 10°E (+-); (3) above normal indices at both 50°W and 10°E (++); and (4) below normal indices at both 50°W and 10°E (--). The relationship between initial regime and overage resulting 30-day forecast anomaly correlation is displayed in Table 1.

Table 1: 30-day forecast anomaly correlation (AC) as a function of initial weather regime.

Initial Zonal Index Anomaly		Number of	Average 30-day forecast
50°W	10°E	Cases	AC
-	+	9	0.50
+	-	9	0.25
+	+	5	0.34
-	-	7	0.34

It is seen that defining initial regime in this way discriminates in advance between average unskillful 30-day forecasts and, on the average, marginally skillful forecasts. Attention is henceforth focused upon the "-+" and "+-" initial regimes, since the remaining regimes ("++" and "--") yield, on the average, 30-day forecast AC near the sample mean (0.36). A comparison of forecasts and observations reveals that the "+-" initial regimes are followed, in time, by intense (often rapidly developing) and poorly forecast surface cyclones over the Atlantic. The interaction between cyclone- and planetary-scale waves, as measured by its contribution to quasigeostrophic 500 mb height tendencies (Holton, 1979) is poorly simulated by the CCM in these cases by five days in advance of the initial time. Rapid synoptic-scale and then planetary scale error growths ensue with consequential loss of forecast skill by day 10.

Following the "-+" initial regimes, surface cyclone activity over the Atlantic Ocean is less intense and better forecast. The synoptic-to-planetary-scale interaction, as defined above, is well simulated out to ten days in advance, error growths are more restrained and forecast skill is retained through day 10.

It is thus hypothesized that skillful 30-day forecasts by numerical models require accurate model forecasts of cyclones through day 10 (i.e. at medium range), and that this may be more likely under certain initial regimes (weaker than normal

500 mb westerlies over Atlantic Ocean storm track with faster than normal 500 mb westerlies over Europe) than others. The skill discrimination noted here is also found in the initial regimes of the NMC 30-day forecasts (Tracton et al., 1989) overlapping with the NCAR data set, suggesting that it may not just be indigenous to the NCAR CCM. It can also be applied to operational medium-range forecasts such as the NMC 6-10 day outlook.

Further research should be directed toward extending the range at which cyclones, particularly those which are rapidly intensifying, can be accurately predicted, and understanding the sensitivity of these cyclone forecasts to initial conditions.

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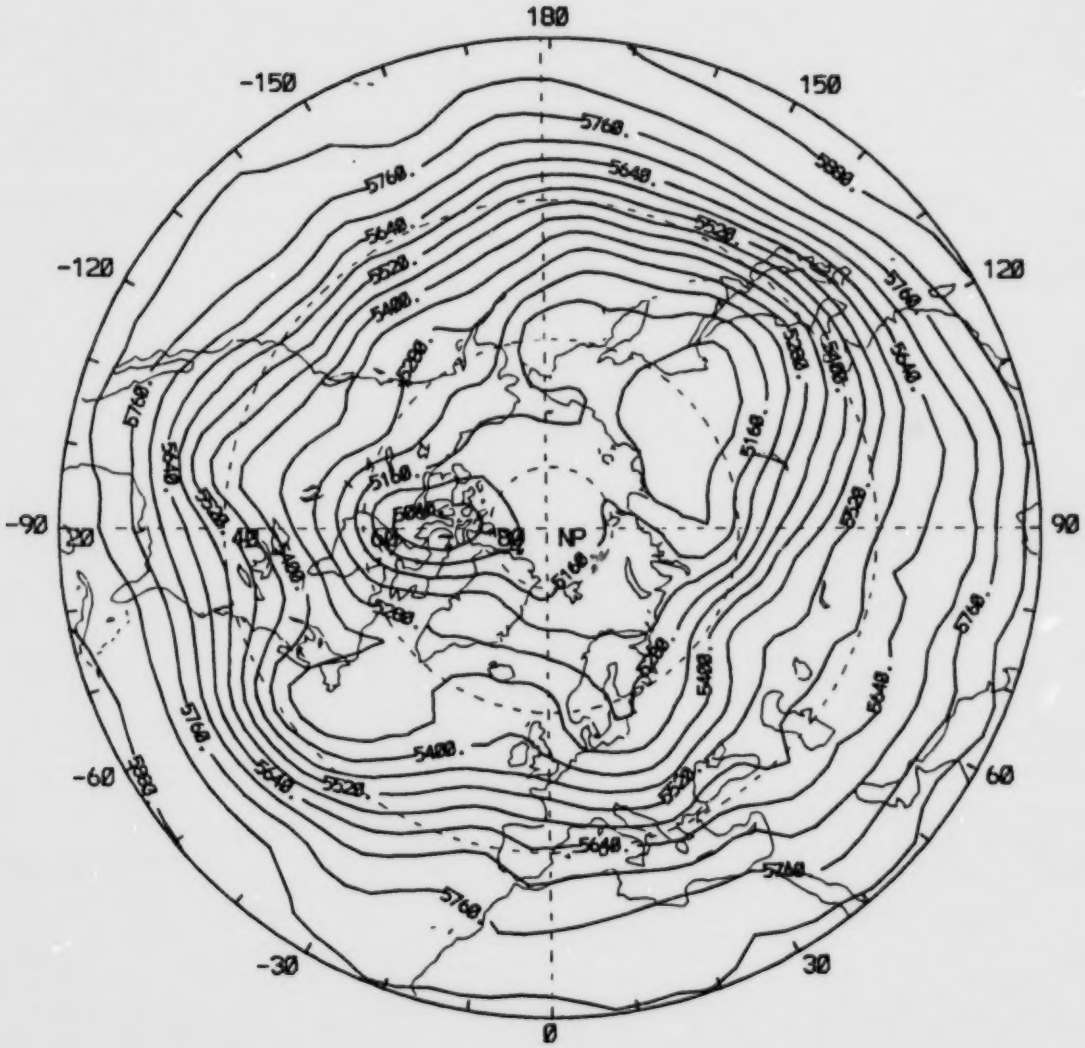

Figure 1: Composite initial 500 mb heights (meters) of the five best 30-day forecasts.

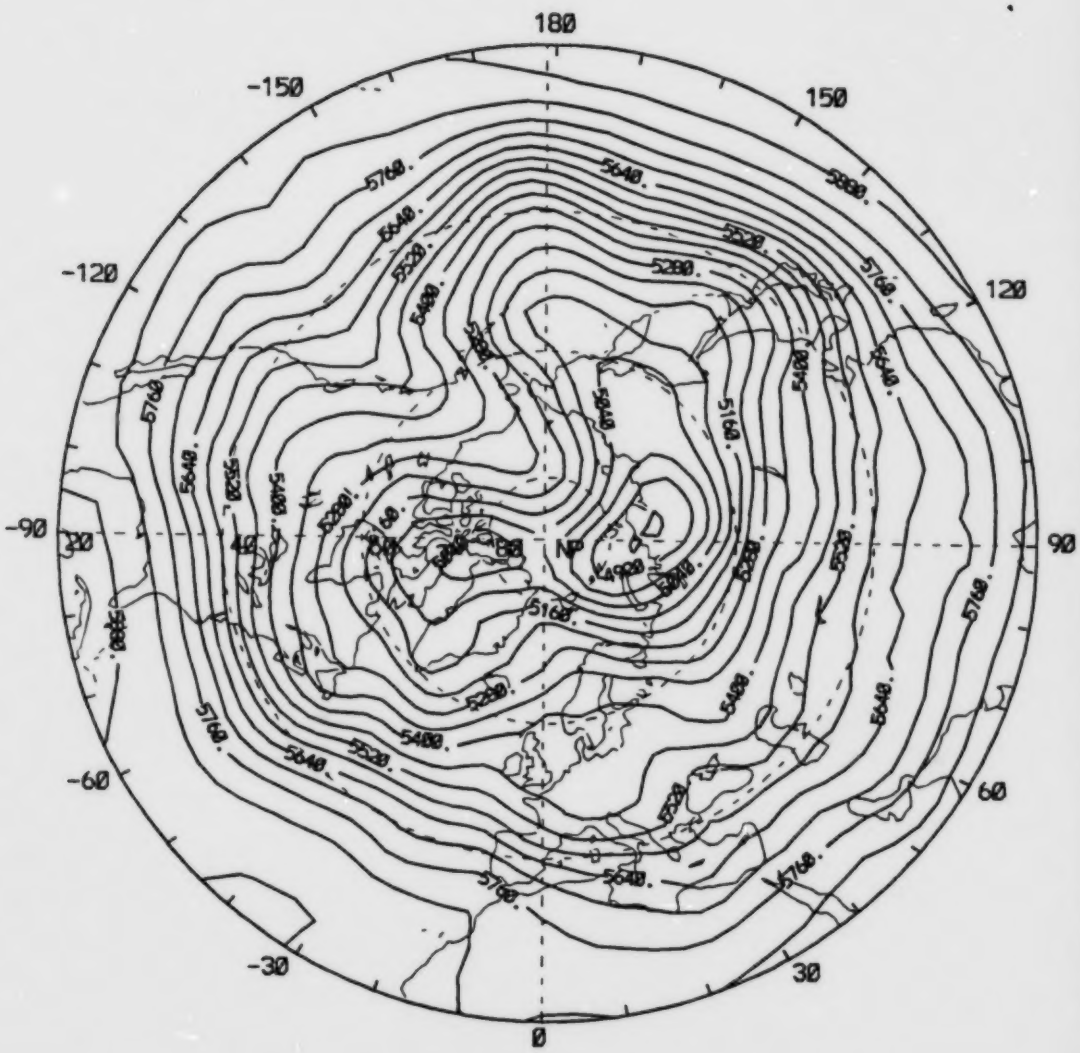

Figure 2: As in Fig. 1, but for the worst five 30-day forecasts.

PROSPECTS FOR SHORT-TERM AND MESOSCALE NUMERICAL FORECASTING — A BASIC RESEARCHERS PERSPECTIVE

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ABSTRACT

Basic research experience simulating a variety of mesoscale weather systems with the Colorado State University Regional Atmospheric Modelling System (RAMS) is described. The results of those studies indicate the opportunities for advances in mesoscale forecasting that can be expected in the next decade. Experience in computing on both supercomputers and super-workstations is summarized. We propose that weather forecast systems in the future should consist of a single multi-national global forecast center and distributed, super-workstation-based regional forecast centers.

Résumé

Des expérience de recherche de simulation de divers systèmes météorologiques de la mésoéchelle conduites avec le " Colorado State University Regional Atmospheric Modelling System " sont décrites. Les résulats de ces études indiquent les possibilités d'améliorations de la prévision à la mésoéchelle à venir dans la prochaine décennie. Des expériences ont été réalisées avec des superordinateurs et avec des super " stations de travail "et elles sont présentées ici. Nous proposons que , dans le futur, les systèmes de prévision du temps prennent la forme d'un centre multi-national unique de prévision globale et de centres régionaux de prévision utilisant des super" stations de travail".

INTRODUCTION

The Colorado State University Regional Atmospheric Modelling System is a multi-purpose mesoscale and cloud model used to support basic research. It is structured in a modular form with a variety of physical modules containing explicit treatments of cloud microphysics, atmospheric radiative transfer through clear and cloudy atmospheres, soil moisture and vegetative canopy effects on the surface energy budget, and parameterizations of boundary layer turbulence, deep convective clouds, and transport and dispersion.
In this paper we investigate the potential of performing realtime mesoscale forecasts with a model system such as RAMS based on our experience of simulating a variety of weather phenomena. We also examine the advantages and disadvantages of performing NWP mesoscale forecasts on centralized supercomputers versus distributed super-workstations. We conclude by proposing a model of a weather service of the future.

SUMMARY OF RAMS FEATURES

RAMS is a completely new computer code that is derived from the merger of two modeling programs, one the cloud modeling program under the direction of William R. Cotton (Tripoli and Cotton, 1980, 1982, 1989; Cotton *et al.* 1982, 1986), and the second the mesoscale modeling program directed by Roger A. Pielke (Pielke, 1974; Mahrer and Pielke, 1977; McCumber and Pielke, 1981). RAMS can be run either hydrostatically or non-hydrostatically, and contains an interactive grid-nesting capability allowing a large number of telescoping or a number of non-telescoping grids. RAMS can be initialized with a horizontally-homogeneous sounding or by the objective analysis of a network of soundings (see below).

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EXAMPLES OF MESOSCALE CASE STUDIES

In support of the basic research at CSU, RAMS has been applied to a number of case studies which provide some indication of the potential of using a non-hydrostatic model with explicit cloud physics, and sophisticated radiation and surface energy budget scheme. Because it is designed to support basic research, more complicated physical modules and higher spatial resolution can be used than can be afforded in an operational environment. Moreover, a number of runs can be made correcting analysis errors which cannot be done in an operational setting. In all these cases, RAMS has been initialized with an objective analysis of NMC grid point data and rawinsondes except for the polar low simulation.

Prediction of the Genesis and Evolution of an MCC

During the Cooperative Convective Precipitation Experiment (CCOPE) in eastern Montana, a mesoscale convective complex (MCC) formed from convection originating in central Montana during the night of 2-3 August 1981. This system did not produce much hail or flooding, but it was a derecho event with numerous reports of strong straight line winds as it propagated through the Dakotas and Minnesota. The MCC was unusual in that the system formed in a baroclinic and highly sheared environment.

As part of our NSF-sponsored basic research investigating the genesis of MCC's, RAMS was set up as a regional forecast model. The initial data for the RAMS simulation was prepared with an isentropic data analysis package described in detail by Tremback (1990). Data sets accessed for the analysis included the NMC global analyses, archived rawinsondes, and 30 minute topography data. All fields were interpolated to isentropic levels where a Barnes objective analysis was performed. Because of the lack of routine measurements, the initialization of the soil temperature and moisture was accomplished with a simple algorithm based on surface station observed relative humidity.

The simulated MCC behaved similar to the observed system in several aspects. Perhaps the most surprising agreement came in the transformation of the convective region of the system from an east-west line oriented parallel to the shear to a north-south line oriented perpendicular to the shear. Figure 1a shows the 3.74 km ASL vertical velocity at 0400 UTC as a depiction of the location and orientation of the strongest mesoscale signature of the convective region, while Figure 1b shows the NWS radar summary at 0435 UTC. Good agreement can be seen between the model and observations. Similarly, the 1200 UTC model results (Figure 2a,b) and 1135 UTC radar summary agree very well.

The model was, however, sensitive to aspects of the model formulation and initial conditions which were approximated for the simulation. For example, by making soil moisture wetter over the Rocky Mountain region, it eliminated the MCC.

Prediction of Middle and High Clouds

In support of a AFOSR-sponsored project to investigate the basic physics of cirrus clouds and to examine the predictability of cirrus clouds, RAMS was applied to the 28 October 1986 cirrus case observed during the FIRE I experiment. Using the above described objective analysis procedure, three nests were activated, with 135 km, 45 km, and 15 km resolution. The upper level cirrus predicted over the Lake Superior region corresponded to a region of predicted upward motion, which corresponds to a region of observed extensive cirrus coverage. Moreover, the model predicted a region of sinking motion over central Wisconsin which corresponded to observed clearing of the cirrus.

The model also predicted a low-level (1.25 km) layer cloud over North Dakota and Minnesota which corresponds to an observed stratocumulus cloud in the region, but was not able to simulate an observed layer of thin cirrus (200 m) at the 11.3 km level. This may have been due to inadequate vertical resolution (500 m) used.

Prediction of Orographic Snowfall

As a part of the ARO Geophysical Science Center, we have been evaluating the usefulness of RAMS for quantitative precipitation forecasting (QPF) of snow and rainfall. In this study we apply RAMS to a heavy

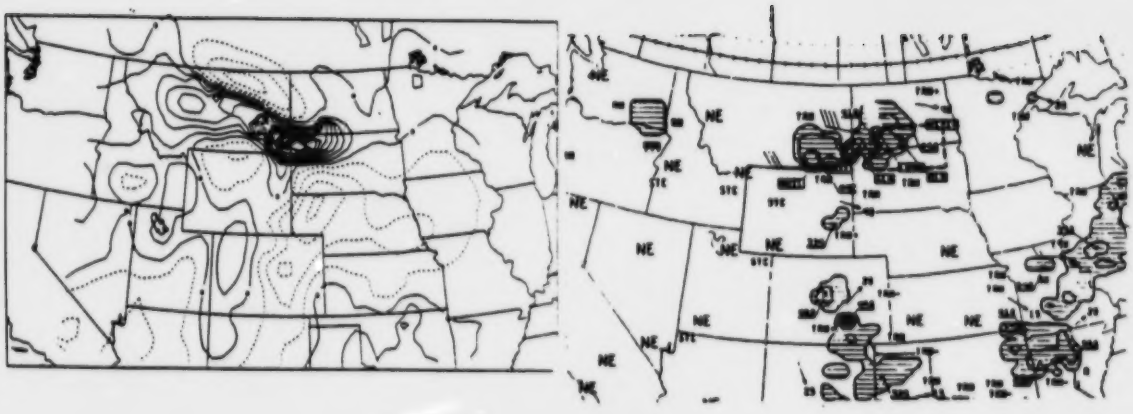

Figure 1: a. Vertical velocity on the 3.74 km ASL level from the model simulation at 0400 UTC, 3 Aug 1981. b. National Weather Service radar summary for 0435 UTC, 3 Aug 1981.

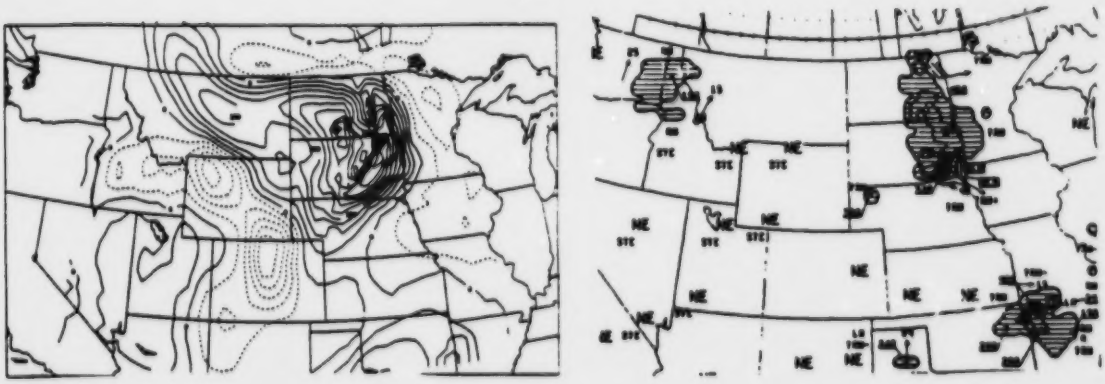

Figure 2: a. Same as 1a, except 1200 UTC. b. Same as 1b, except 1135 UTC.

precipitation event over the Sierra Nevada. A prolonged orographic precipitation event, in a relatively steady-state synoptic environment, occurred over the Sierra Nevada range in central California on 12-13 February 1986. RAMS was initialized with the above described objective analysis procedures with 5 km horizontal resolution of the inner grid and 20 km on the coarser grid. The vertical grid was stretched from 250 m in the lower levels to 750 m above the barrier top. The simulation was run with full microphysics on only the coarse grid during the first hour, but included the inner nest out to 3 h. Winds at 0.5 km after 3 hr of simulation AGL exhibited a strong south-southeasterly componen, or "barrier jet" over central California similar to the observed 22 m s^{-1}. The simulated precipitation rate exhibits a precipitation maximum (3.2 mm h^{-1}) oriented along the middle half of the western slope of the Sierra barrier. Amounts over the Sacramento Valley over the western domain and to the lee of the barrier are less than 1 mm h^{-1}. These results are in good agreement with observed precipitation rates with a more pronounced meridional variation.

Polar Lows

In a completely new meteorological application for the model, Torben Pedersen has applied RAMS to an observed polar low case over the northeastern Atlantic. Modifications to RAMS to support this research included the addition of a sea ice surface parameterization and a polar stereographic coordinate projection. RAMS was set up with 50 km, 25 km, 12.5 km grids. Beginning with the HIRLAM model analyzed synoptic data fields, RAMS developed a deeper low than any previous simulation of the case though still not as deep as the observations. Also the position of the low was off somewhat but the errors can be attributed to weaknesses in the HIRLAM model analyses used as input to RAMS. Overall the results were encouraging and revealed the formation of banded precipitation patterns similar to observed, that have not been simulated before. Mechanisms responsible for the formation of those bands are now being examined.

Summary

Overall the results of applying RAMS to the above cases were quite encouraging, yielding some optimism that a non-hydrostatic model with explicit cloud physics can improve routine forecasting of clouds and mesoscale weather. The results also indicate that the analysis of larger scale data, refined horizontal resolution, and surface conditions (i.e., soil type and moisture content, sea ice cover, etc.) are the most important aspects of mesoscale prediction. The greatest physics in the world cannot overcome a bad initial analysis in most circumstances. Improvements in terrain resolution, cumulus parameterization, and refinements in cloud microphysics is next in order of priority.

SUPERCOMPUTERS VERSUS SUPER-WORKSTATIONS

In the above studies and in many of our basic research investigations, RAMS is run on either a supercomputer such as the CRAY X-MP or CRAY 2 or on a super-workstation such as the ARDENT TITAN. In the configurations described above, RAMS performed a 24 hr forecast on a 44 km mesh in the MCC case in 4 hrs on the CRAY X-MP, in the three-nested cirrus case with a 15 km mesh activated for only 1 hr on the Cray X-MP it took 2 hrs to do a 24 hour simulation; in the single-nest 50 km mesh polar low case on the CRAY 2, it took 2.4 hrs for 24 hrs of simulation, but the triply-nested polar low case run for the full 24 hours, took 36 hrs for 24 hrs of simulation; in the two-nested orographic case with 15 km resolution on the CRAY X-MP it took 48 hrs to do 24 hrs of simulation. The differences in computational time are a result of the size of the grids, the number of grids points in which the explicit cloud microphysics is activated, and the time that a fine grid is activated. With about three to six man-months of effort in code optimization and simplification in model physics, we estimate RAMS could readily be used as a forecast model on the Cray computers, even with 15 km resolution in a fine nest covering 200-400 km for 6 to 12 hours.
The same configuration of RAMS on our Ardent Titan on a single P-2 processor runs 1/15th the speed it does on a CRAY X-MP single processor. We estimate that the same code would run 1/7th the speed of a single processor Cray if a Stardent with P-3 processors were used. Furthermore, we estimate that by developing parallel algorithms in RAMS, a 4-processor Stardent with 128 M-bytes of memory will perform the same calculations in roughly the same speed as a single processor Cray X-MP. In other words, *as long*

as a memory-contained code can be used, a super-workstation can be used for mesoscale forecasting. This is a complete system with over 2 Giga-bytes of disk space for less than $200,000!
The workstation also supports interactive operation of the forecast model so that telescoping or moving grids can be activated by the user during the simulation. Interactive editing of input data can be done during data analysis and four-dimensional data assimilation. Furthermore, a super-workstation is an ideal environment for displaying model output data, allowing animation of model output products. We estimate to optimize, parallelize, and set up a code such as RAMS for interactive real-time processing will take about six man-years of software engineering. This is the price one must pay to achieve fast, convenient, interactive numerical mesoscale forecasts on a super-workstation.

PROPOSED WEATHER FORECAST SYSTEM IN THE FUTURE

Currently most if not all weather services are built on the concept of a centralized forecast guidance system in which global and regional models are all run on the same central super-computer.
We propose the following model in which only global forecasts are produced at a centralized forecast facility. These forecast data as well as analysis fields are then distributed to a network of regional forecast sites where super-workstations are located. Nested-grid forecast models at those sites can be initialized with the central model output or analysis products. Mesoscale forecasts could be produced interactively with 10 to 15 km resolution over a 200-400 km domain for 6 to 12 hr periods. A major function of the regional center meteorologists will be to perform four-dimensional data assimilation of special mesoscale data in the region and produce animated analysis products for dissemination to the public and user community.
The particular configuration of the mesoscale model may differ from region to region depending on the regional climate, topography, and physiography. But each regional model will be configured out of the same source code, therefore requiring maintenance of only a single code rather than 20 or 40 different codes.
One advantage of this model is that a number of countries could band together like ECMWF and produce central global products (i.e. a North American global and mesoscale forecast center). The individual countries could share the costs of operating the global forecast center and then operate and maintain the network of regional forecast models at far less expense. Research and development of regional or mesoscale forecast models, however, should be done at the global center. Some smaller countries, such as Costa Rica would then have to maintain only a single workstation-based mesoscale forecast model. It just doesn't make economic sense to have a proliferation of global forecast models as is the current trend!

ACKNOWLEDGEMENTS

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A REAL-TIME MESOSCALE MODELING SYSTEM USED FOR FORECASTER TRAINING AND MULTICASE EVALUATION OF RESEARCH RESULTS

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INTRODUCTION

There are two ways in which research by university atmospheric modeling groups can benefit operational forecasting centers; by transfer of new modeling technologies and by forecaster training. Unfortunately, neither of these have proved to be very effective. One problem is related to the fact that a multicase evaluation of each new modeling technique is required for a wide range of meteorological settings before it is ready for operational implementation. This has generally not been done because of the logistical difficulties associated with performing many real-data simulations with a research model. Additionally, training of forecasters in the use of these models, which resemble the next-generation operational models, has not been possible because the research models have not been run in real time to emulate an operational setting.

In order to remove these obstacles, a version of the Pennsylvania State University/National Center for Atmospheric Research (PSU/NCAR) mesoscale model is now being run routinely in real time at Penn State (Warner and Seaman, 1990). This daily, real-time operation of the mesoscale model allows automatic generation of many cases for model verification, ensuring that newly developed software is tested on a representative cross section of atmospheric conditions. This is especially important because various versions of this model are already used extensively at Penn State for research involving parameterization procedures, numerical techniques, four-dimensional data assimilation, and physical-process diagnosis. There are equally important additional benefits to running the research model in real time. One is that the research modelers have the opportunity to interact with operational forecasters in the Departmental weather station and learn from their subjective evaluation of the model's skill. Secondly, the fact that the model output is from a mesoscale model that currently has a horizontal resolution which is roughly three times that of the current operational regional model of the U.S. National Weather Service (NWS) enables us to evaluate how forecasters will utilize output from future operational models in the weather stations of the next decade. Lastly, we can utilize the real-time digital numerical products from the mesoscale model in dynamics and weather-

forecasting courses to better train the students who will soon be using the next-generation numerical products from the National forecast centers.
In the next section we will describe the modeling system and show an example of the forecasts. This will be followed by a discussion of how the mesoscale numerical guidance is being used in forecaster training and research.

CHARACTERISTICS OF THE MESOSCALE MODELING SYSTEM

The numerical and physical characteristics of the mesoscale model now being run routinely in real time are very similar to those used in model versions presently employed in purely research settings. Specifically, a nested grid system is used with a two-way interacting interface, where the fine-grid increment is 30 km and the coarse-grid increment is 90 km. The fine grid has dimensions of 43 x 43 points, while the coarse grid is defined by a 41 x 41 point mesh. Figure 1 shows the geographic coverage of the most frequently used grid system. The resolution and position of the fine grid were chosen so that mesoscale processes such as Appalachian cold-air damming, Great Lake effects, coastal fronts, and coastal cyclogenesis can be represented. There are 15 computational levels with sufficient resolution in the lowest kilometer to allow representation of the boundary-layer processed important to the above-noted mesoscale phenomena. Realistic, seasonally adjusted fields of soil and vegetation characteristics are employed to determine the surface thermal inertia, roughness, albedo and emissivity. Surface wetness and snowcover are defined for each forecast based on observed conditions. The sea-surface temperature field is defined based on the NOAA 14-km experimental analysis and is periodically adjusted to account for the slowly evolving structure of the Gulf Stream warm and cold gyres and the strong temperature gradient on its northwest edge.

Figure 1. Coarse-grid domain (outer border) with a grid increment of 90 km, and fine-grid domain (inner border) with a grid increment of 30 km.

Initial data for the model are obtained in real time from the same NWS data circuits that routinely serve the Meteorology Department's educational and public-service functions. Lateral boundary conditions for the coarse grid are based on the forecast from the Nested Grid Model of the NWS. The forecast can be initiated at either 00 UTC or 12 UTC, and generally extends for 36 h. A forecast of this

duration requires about three hours of CPU time when the computations are performed in single-precision arithmetic on one processor of the IBM 3090/ES-600S located on the Penn State campus.

As an illustration of the kind of mesoscale detail available from this model, Fig. 2 shows the real-time forecast for the period from 0000 UTC 28 November to 1200 UTC 29 November 1989. During the last six hours of this 36-h forecast period, a convective band generated moderate snowfall that extended from Lake Erie towards southeastern Pennsylvania. It produced two inches of snowfall in State College, PA (geographic center of PA) during approximately a three-hour period. The upper-left panel in Fig. 2 shows the observed surface conditions for 1200 UTC 29 November 1989, the ending time of the forecast, and illustrates a distinct surface-pressure trough to the southeast of Lake Erie, with a weaker trough over southwestern New York State associated with Lake Ontario. Streamlines constructed from the observed surface winds show confluence zones to the southeast of Lakes Erie, Ontario and Huron. The precipitation rate at this time is reflected by the visibility, which is observed at the surface airways stations. Visibility of less than three miles is shaded, indicating heavier snowfall rates to the southeast of Lakes Erie and Huron. In the upper-right panel is the model forecast of surface conditions for the same time. Surface-pressure troughs are forecast to the lee of all three lakes, as are confluence zones in the wind field. During the last 6 h of the forecast, a band of snowfall is predicted from Lake Erie to southeastern Pennsylvania, and snowfall is predicted along the lee shores of Lakes Ontario and Huron. The shaded area indicates 6-h precipitation totals in excess of one millimeter liquid equivalent, or about one-half inch of snowfall. Embedded within these broad bands are areas with accumulations in excess of two millimeters liquid equivalent, or about one inch of snowfall. The lower-left panel is a nephanalysis for 1501 UTC 29 November, showing the existence of deeper convective clouds oriented nearly parallel to the surface streamlines to the lee of the lakes. The lower-right panel shows 700-mb height and relative humidity for 1200 UTC 29 November. As expected, distinct humidity maxima are predicted to the lee of each of the three lakes. The existence of the greatest relative-humidity maximum over Pennsylvania is interesting in that it may have resulted from the preconditioning of the air flowing over Lake Erie by heat and moisture fluxes from Lake Huron. Certainly the surface streamlines support this idea, showing that the Lake Erie, but not the Lake Ontario, boundary layer air was potentially modified by Lake Huron. In summary, the model was able to predict the occurrence of this mesoscale convective event over 30 h in advance. Predictions with such detail and accuracy are fairly common, and add a totally new dimension to the process by which forecasters use the model output for guidance. This is discussed in further detail in the next section.

FORECASTER TRAINING AND RESEARCH STUDIES WITH THE MODEL

Forecaster Training

Thus far, the real-time mesoscale model has been used for training of students in two meteorology courses. Both courses involved training the students in techniques for

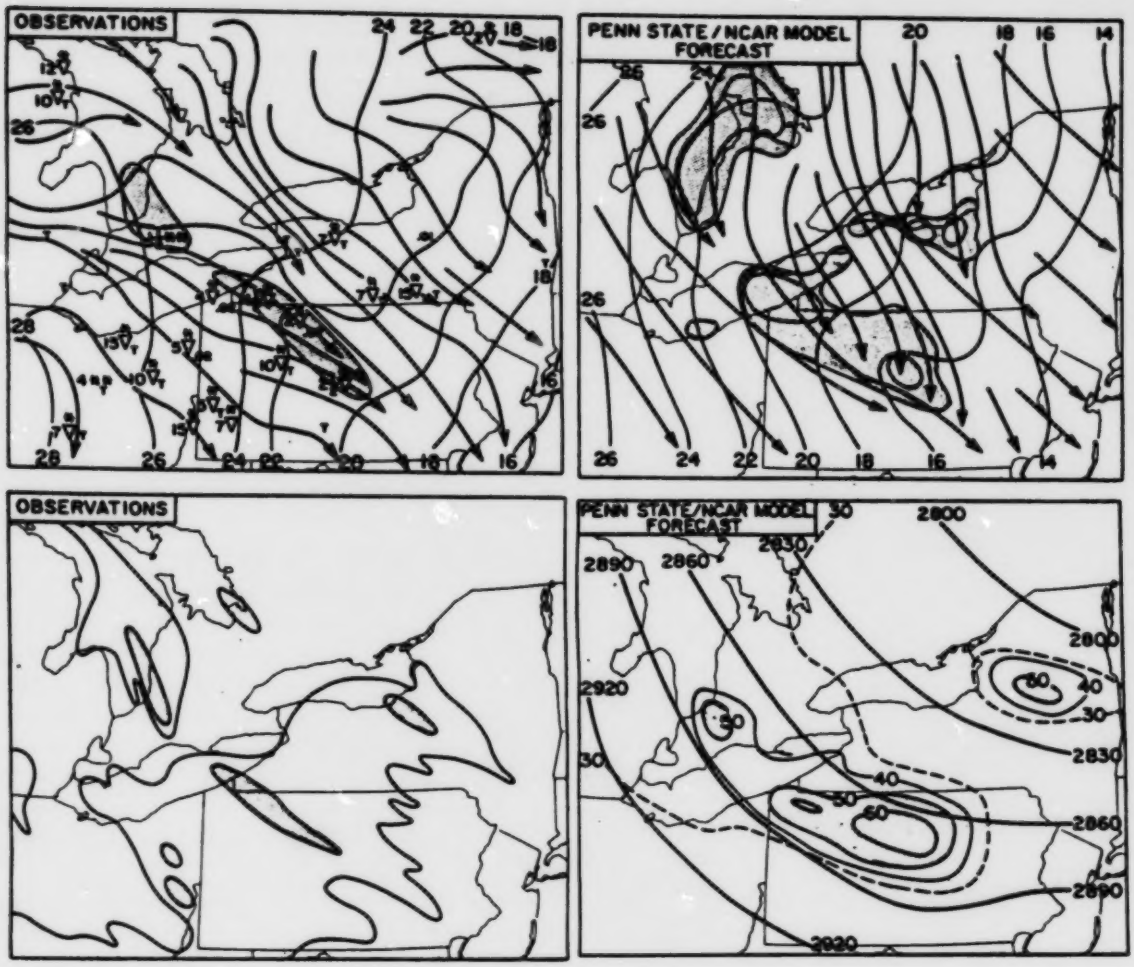

Figure 2. Upper left -- observed conditions for 12 UTC 29 November 1989: sea-level pressure (mb+1000) showing thermally induced trough from Lake Erie to southeastern Pennsylvania and a weaker trough to the southeast of Lake Ontario; surface streamlines illustrating northwest/southeast-oriented confluence zones to the southeast of Lakes Erie, Ontario and Huron; symbols showing 6-h precipitation (cm) snow-showers and visibility (mi), shading for areas with visibility of three miles or less. Upper right -- 36-h prediction from the mesoscale model for 1200 UTC 29 November 1989 of sea-level pressure (mb+1000) showing the two lee-side troughs; surface streamlines showing confluence zones to the lee of each of the three lakes; 6-h precipitation accumulation from 06-12 UTC 29 November (shaded--greater than 1 mm, line inside shading--greater than 2 mm liquid equivalent). Lower left -- nephanalysis for 1501 UTC 29 November showing shallow low cloud (outer solid line) and deeper convective cloud (shaded). Lower right -- 36-h prediction from the mesoscale model for 12 UTC 29 November of 700 mb height (heavy solid lines, m) and relative humidity (light lines, dashed line-30%, shading above 50%).

preparation of operational weather forecasts, but one emphasized mesoscale phenomena and the other synoptic-scale phenomena. In both cases, the experienced instructors found that considerable learning was also required on their part because the high-resolution model was predicting meteorological structures that they had previously not had to consider in their process of evaluating numerical-model guidance. That is, conceptual models of various mesoscale processes had to be sharpened, and a more multiscale approach to interpretation of the numerical guidance had to be developed. It should be emphasized that this was more than the usual learning process that a forecaster always requires when he is getting acquainted with the idiosyncrasies of a new model. For example, this was the first time in the instructors' many years of forecasting experience that they were able to identify in the "operational" numerical guidance the detailed structure of locally forced phenomena associated with the Great Lakes, the Atlantic coastline, the Gulf Stream, and the Appalachian topography. A totally new dimension had been added to the available guidance.

Without new ways of interacting with the mesoscale model output, much of its value is lost to the forecaster. For this reason, hourly digital data of all the predicted variables (temperature, humidity, pressure, precipitation and winds) are available for interactive analysis using a menu-driven graphics program on microcomputer workstations. The unsmoothed model grid-point output is available on the original model coordinate surfaces (terrain following), on pressure surfaces, and on cross sections with any orientation. Time-height sections and time plots of variables are also available for any point on the forecast domain. This graphics capability is accessible to students on over 25 graphics workstations in the Department's weather station. In addition, for each forecast, a 36-h color-enhanced animation is produced using the hourly fields of sea-level pressure and hourly precipitation amount. These animated displays are proving to be extremely effective at presenting model output to student forecasters and staff in a user-friendly format. Such innovative and interactive approaches to interrogation of the model output are necessary to help prevent the model user from being overwhelmed by the five million words of model output that constitute the output data set from a 36-h forecast. As challenging as the task has been of developing effective interactive forecast visualization techniques, it has indeed been worth the effort because it has allowed our student forecasters and staff to actually "touch" and manipulate the direct output from an operational model for the first time.

Research Applications

In addition to the fact that it is more convenient to perform multicase testing of hypotheses or new modeling techniques using a model being run in real time, there are other advantages as well. For example, it provides a setting in which modelers, operational forecasters and diagnosticians can interact to better understand mesoscale processes and how to predict them. The fact that the model runs in real time also presents unique opportunities for collaboration with other research and operational forecasting groups. For example, we are providing numerical guidance this winter to the participants of the Lake Ontario Winter Storms (LOWS) experiment, who use our forecasts of lake-effect precipitation to help manage their measurements program. Also, the mesoscale-model forecasts are made available to the National Weather

Service and River Forecast Offices in Harrisburg, PA, to the Weather Service Forecast Office in Philadelphia, PA and to the National Meteorological Center Operations Division in Washington, DC. Feedback about model performance from the experienced career forecasters in these offices has been stimulating and rewarding. In addition, after an improved warm-season precipitation parameterization has been included in the real-time version of the model, real-time forecasts for the midwest U.S. will be provided on an experimental basis to forecasters at the National Severe Storms Forecast Center in Kansas City, MO. This will provide an excellent setting in which to test the new parameterization on a large number of cases. A final point can be made about the opportunities now available to examine how mesoscale model output can be best utilized in the weather stations of the future. The major focus of this type of research would be the process by which the mesoscale model output, the data, and conceptual models are utilized by operational forecasters when making short-range or very-short-range forecasts.

SUMMARY

In this paper we have described an experimental real-time mesoscale numerical weather-prediction facility at Penn State, and have emphasized its impact on forecaster training and research. The real-time mesoscale modeling system provides the students with an opportunity to gain experience making operational forecasts with the guidance of a model comparable to the next-generation operational regional model of the NWS. Also, an interactive graphics system permits forecasters to easily manipulate the primitive digital model output that are nominally available every hour. The student forecaster can thus focus on specific forecast variables, geographic regions, or time periods within the forecast, and choose a number of options for creatively displaying the information. These real-time forecasts also provide new and exciting opportunities for mesoscale modelers, operational forecasters and mesoscale diagnosticians to jointly evaluate optimal ways in which mesoscale forecasts can be used in weather stations of the future.

It should be emphasized that we view this real-time mesoscale modeling system as experimental. Even though a working system has been in place for about a year, the most exciting phase remains ahead: learning creative new ways to use it in teaching and research endeavors. A high priority is sharing these real-time forecasts, for perhaps a variety of geographic areas, with scientists from other laboratories and educational institutions.

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THE WEATHER FORECAST MODEL OF THE NEXT CENTURY

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Vers le modèle de l'an 2000.

Tous les modèles de prévision numériques utilisés à ce jour sont basés sur un ensemble d'équations approximées et, par ce fait, de portée limitée. L'approximation principale, dite d'hydrostaticité, vise à éliminer la propagation verticale des ondes acoustiques admises par les équations exactes. Ces ondes ont une vitesse de propagation tellement grande que leur inclusion nécessiterait, avec les schémas numériques standards, une réduction du pas de temps du modèle, et donc une augmentation du temps de calcul, par un facteur mille par rapport aux modèles hydrostatiques. L'approximation hydrostatique, quoique très pratique et acceptable pour les prévisions à grande échelle, cesse d'être valable lorsque la maille des modèles devient de plus en plus fine: c'est le cas par exemple pour la modélisation aux échelles méso-bêta et plus fines. Même pour le modèles globaux, on peut anticiper qu'au taux actuel d'augmentation de résolution des modèles permise par la vitesse accrue des super-ordinateurs vecteurs, la limite de validité de l'approximation hydrostatique sera atteinte durant la prochaine décennie, et elle devra alors être enlevée. Il devient donc pressant de trouver une méthode efficace pour intégrer les équations de fluides non-hydrostatiques (équations d'Euler).

Les équations d'Euler sont déjà utilisées en recherche pour simuler les échelles convectives dans l'atmosphère. Toutefois l'intégration de modèles basés sur ces équations est extrêmement coûteuse au point de vue du temps de calcul requis, même sur les super ordinateurs. Une étude préliminaire visant à démontrer la faisabilité d'une accélération substantielle de ces modèles a été réalisée récemment à l'UQAM en collaboration avec le Service de l'environnement atmosphérique du Canada (Tanguay, Robert et Laprise, 1990).

Abstract

All weather forecast models to this day have been based on an approximate set of the true equations, and this factor limits the scope of their applicability. The main approximation, that of hydrostaticity, was introduced in order to eliminate vertically propagating acoustic waves from models. The phase speed of these waves is so large that their incorporation in standard numerical models would require a reduction in their timestep, and hence an increase the required computer time, by a factor one thousand compared to hydrostatic models. The hydrostatic approximation, indisputably adequate for large-scale forecast models, ceases to be acceptable when mesh sizes become finer: this is the case when attempting to model meso-beta or smaller phenomena. Even for global models, the continued trend of increasing resolution that ever faster computers allows, will push the resolution of these models beyond the limit of validity of the hydrostatic approximation within the next decade or so. Beyond that point, the models will have to be based on the fully compressible (Euler) equations: it thus becomes imperative to find efficient means of integrating these equations.

Introduction

The Euler equations have already been used to simulate convective scale disturbances in models of the atmosphere. The integration of these models is however extremely costly in terms of computational resources, even on today's fastest computers. A preliminary study carried out at UQAM has demonstrated the feasibility of accelerating substantially such models. The algorithm employed consists in an extension of the semi-implicit algorithm which use is widespread in hydrostatic models.

Standard means of integrating models consists in the use of explicit timestepping technique such as the "leap-frog" marching scheme, in which time derivatives are discretized using a second-order accurate approximation:

$$\frac{dF}{dt} = \frac{F(t+\Delta t) - F(t-\Delta t)}{2\,\Delta t} + O(\Delta t^2)$$

and the terms contributing to the tendency $\mathbb{R}$ are evaluated at the centred point in time:

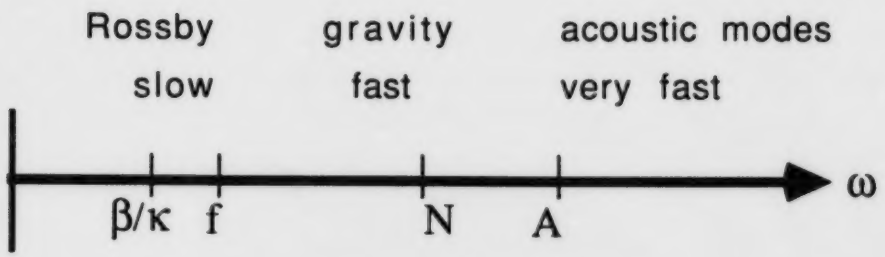
$$\frac{dF}{dt} = \mathbb{R}\,(\,F(t)\,)$$

An analysis of such a scheme (e.g. Haltiner and Williams, 1980) reveals that it is only conditionally stable: it "blows up" when the timestep Δt exceeds the period of the phenomenon modelled. It is thus paramount to know something about the type of oscillations admitted by the meteorological equations.

Atmospheric waves

Three types of waves can be sustained in the (electrically neutral) atmosphere: in order of decreasing period and wavelength, these are the Rossby (or synoptic) waves, the gravity waves and the acoustic (or sound) waves. Rossby waves of physical significance have wavelength ranging from somewhat less than a thousand kilometers to the scale of the planet: their periods vary from about an hour to the inertial period. Gravity waves cover a very wide range of scales (atmospheric tides, mountain lee waves, turbulent eddies, etc); the period of internal waves is a function of the static stability, being of the order of one minute in standard conditions. Acoustic waves are much more elusive and travel at very high speed (the speed of sound is of the order of 350 km per hour): for a vertical spacing between model levels of the order of a kilometer, information propagates on timescales of the order of one second.

It is this great discrepancy between the timescales of the modes of oscillations in the atmosphere which makes the integration of the Euler equations expensive with explicit marching schemes.



Types of waves in the atmosphere and their frequencies.

The semi-implicit algorithm applied to the Euler equations

The semi-implicit algorithm exploits the fact that the most significant waves are the slowest ones; this statement is still true even at mesoscale. The essence of the method is to numerically modify the dispersion relationship of atmospheric waves to accommodate the timestep. The semi-implicit algorithm consists in breaking the tendency terms $\mathbb{R}$ into a linear part $\mathbb{L}$ responsible for oscillations and a remainder comprising all the other nonlinear terms $\mathbb{N}$, and in treating the linear terms as averages-in-time and the nonlinear ones as centred-in-time as in the explicit case:

$$\frac{dF}{dt} = \mathbb{R} = \mathbb{L}\left(\frac{F(t+\Delta t) + F(t-\Delta t)}{2} \right) + \mathbb{N}(F(t))$$

Unlike explicit marching schemes, the semi-implicit algorithm, coupled with the semi-Lagrangian advection scheme, provides an essentially unconditionally stable integration scheme. The timestep can then be selected to achieve a prescribed level of accuracy or to fit within the available computer resources.

Results and prospects for the future

A preliminary study performed using a regional model with minimal physics has shown that, compared with a similar integration of a hydrostatic model, the Euler equations can be integrated without any computational penalty. At large scale, an Euler based model produces forecasts indistinguishable from those of a hydrostatic model. However the same model could then be employed on very fine mesh to produce mesoscale forecasts. The dynamical framework of a model based on the Euler equations has no intrinsic limitation in its applicability to simulate all possible scales in the atmosphere. It then becomes simply a practical question of how much computer power is available to integrate the highest possible resolution model.

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Dynamical framework

Meso-γ	**Meso-β**	**Meso-α**
L_x< 20 km	20 < L_x <200 km	L_x> 200 km
convection mountain waves	Mesoscale convection complexes	GCM Wx forecast models

Buoyancy: gravity waves — Inertia: Rossby waves

Anelastic models **(...)** **Hydrostatic PE models**

$$[\partial_t \rho +] \quad \vec{\nabla} \cdot (\rho \vec{V}) = 0 \qquad [d_t w +] \quad \frac{\partial p}{\partial z} + \rho g = 0$$

Euler Navier-Stokes equations

Rossby, gravity, acoustic waves
slow fast very fast

A BOUNDARY LAYER MODEL FOR SHORT-RANGE WEATHER FORECASTING

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Abstract

A successful short-range forecast in an operational environment depends very crucially upon the quality and quantity of data available, tools to handle the data, alertness of the duty forecaster, and available conceptual models of mesoscale processes, among other things. Many of the current operational problems in short-range forecasting (e.g., thunderstorm outbreaks, prediction of minimum and maximum temperatures, development of low cloud or fog) are controlled in significant part by processes occurring in the planetary boundary layer (PBL). A model of the PBL suitable for short-term forecasting is presented here. This presentation will discuss the boundary layer model, adaptation for use in forecast situations, and examples of case studies of real-time or simulated real-time situations.

Résumé

Le succès d'une prévision à court terme dans un environnement opérationnel dépend , entre autres, de la qualité et la quantité des données disponibles, des outils de prévision de la vigilance du prévisioniste et des modèles conceptuels des processus physiques à sa disposition. Beaucoup des problèmes actuels de prévision à court terme(prévision d'orages, de nuages bas , de brouillard, de températures minimum et maximum) sont régis par des processus de couche limie. Un modèle de couche limite planétaire adapté pour la prévision à court terme est ici présenté. On discutera ensuite de l'adaptation de ce modèle dans des situations de prévision et on présentera des exemples d'études de cas en temps réel ou simulé.

INTRODUCTION

This paper will present modifications of an existing one-dimensional (1D) model of the atmospheric planetary boundary layer which allow it to be used for short-range weather forecasting applications. We will present results of experiments involved in the prediction of boundary layer depth, maximum air temperature, and convective potential using available surface and upper-air data as well as parameterization of larger-scale processes from operational numerical weather prediction (NWP) models and large-scale objective analyses of upper-air data. Sensitivity of boundary layer structure and low-level temperature in particular will also be examined in some detail for several cases.

MODEL DESCRIPTION

The planetary boundary layer model is derived from a formulation of the boundary layer in the global spectral model (GSM) of the Air Force Geophysics Laboratory (AFGL), described by Brenner et al. (1984). The boundary layer formulation (following Troen and Mahrt, 1986) diagnoses h, the boundary layer height, for stable and unstable conditions as a function of the bulk Richardson number of model layers. Figure 1 illustrates the diagnosis of h for the stable and unstable case. Horizontal wind components, potential temperature, and specific humidity are forecast in the boundary layer as a result of turbulent diffusion, e.g.,

$$\frac{\partial \xi}{\partial t} = \frac{\partial}{\partial z}\left(K_\xi \frac{\partial \xi}{\partial z} \right) \qquad (1)$$

where K_ξ is the eddy diffusivity, which is a function of stability and varies for dependent variable ξ. The GSM takes care of other large scale processes and it also has separate parameterizations for gravity wave drag, radiation, clouds, etc. In its pure one-dimensional form, however, in order that effective and realistic sensitivity testing could be carried out, parameterizations for short- and long-wave radiation and boundary layer clouds were incorporated into the 1D model. In addition, the model uses a surface energy balance, soil temperature and volumetric water content, and total canopy water content are predicted following Pan and Mahrt (1987) and Mahrt et al. (1987).

For the model to successfully treat realistic short-term prediction of atmospheric boundary layer structure and surface-air exchanges, large-scale processes must somehow be accounted for. These processes include the effects of the large-scale pressure gradient on the wind components, horizontal and vertical advection of momentum, temperature, and moisture. These effects, while taken care of in the AFGL GSM and other NWP models by the formulations of the large-scale dynamics, cannot be incorporated into a simple 1D model of atmospheric boundary layer structure without some substantial effort. We will discuss separately how we propose to incorporate various large-scale effects into the model in our application in an academic environment and how this would work effectively in the operational environment.

a. Moisture

Several aspects of the hydrologic cycle need to be considered here. First, some information about the soil moisture at two levels (5 cm and 1 m) need to be initialized. We are in the process of developing a parameterization for soil moisture based on an antecedent precipitation index (API) following Saxton and Lenz (1967). Such information is needed because the model partitions the net radiation received at the surface into sensible, latent, and soil heat fluxes (following Oke, 1978, for example). Inaccurate estimates of the latent heat flux will lead to gross errors in the sensible heat flux, which will affect boundary layer growth and low-level temperature. Canopy water content could also be initialized but is set to zero in these runs. Atmospheric water vapor content is initialized by the initial sounding, and the initial cloud cover is specified from the observed conditions.

We will incorporate horizontal advection of moisture by performing a large-scale objective analysis of the field using rawinsonde data received via satellite at Florida State University. The analysis may be performed roughly two hours after observation time and the GEMPAK 4.1 package is used (reference needed) to estimate the vertical profile of horizontal advection of specific humidity at a point over the station of interest.

b. Temperature

The initial potential temperature profile is interpolated to the vertical grid (sigma coordinate) from the initial sounding. Soil temperature at 5 cm is typically set to the initial low-level temperature from the sounding while the 1 m soil temperature is usually set to the average monthly temperature preceding the present month. Both soil temperature and volumetric water content are a function of soil type.

Large-scale temperature advection is incorporated by doing an objective analysis of the temperature field at mandatory levels using GEMPAK, and finding the vertical profile of the temperature advection, as is done for specific humidity.

c. Wind field

Horizontal advection of momentum is included as was described for temperature and moisture. Because vertical motion is non-negligible in general, vertical advection of temperature, moisture, and momentum (initially set to zero), also will be included in the model used here. A realistic profile of the vertical motion for each station used is obtained using the kinematic method, where the divergence profile has been obtained from triangles about a station with a correction applied (O'Brien, 1970). This profile of vertical motion is presently held constant during the short model integration of twelve hours, a feature which we hope to improve in later versions.

The time-dependent geostrophic wind components are obtained from an objective analysis of the geostrophic component of the wind field (initially), and an estimate from the 12 hour forecast of the Nested Grid Model (NGM), run in the United States by the National Meteorological Center of the National Weather Service (NWS). The components evolve slowly and linearly in time. An alternative approach has also been investigated which appears to perform adequately, whereby a quick estimate is obtained from the vertical profile of geostrophic wind at low-tropospheric mandatory levels, extrapolated down to the surface.

d. Summary of initialization steps

In order to run the model at any given site, a rawin-sounding is required (typically providing V, T, and T_d from which u, v, θ, and q are determined for model vertical profile initialization), surface conditions as described above, estimates of large-scale horizontal advection of temperature, moisture, and momentum, and time-dependent estimates of the geostrophic wind. The model simulations would potentially be improved if time-dependent horizontal advection and vertical motion profiles were also included.

The goal of these simulations is to provide detailed forecasts of boundary layer structure and other related aspects of the low-level atmosphere, including aspects of the surface energy balance, low-level clouds, and potential for convection. In these simulations, a high resolution version of the model was used with 58 levels in the vertical, 20 m resolution in the lowest levels, stretching to 100 m at 4 km. The model takes only a couple of minutes to perform a twelve hour run on an advanced personal computer (e.g., Macintosh II) or minicomputer (e.g., DEC microVAX, CDC Cyber 930). The steps described above for initialization could easily be duplicated in an operational environment, provided access to the national data stream and computer time on the local mini- or micro-computer is available.

APPLICATIONS

Several cases have been investigated using the model, including cases run in pseudo-real-time from 1988 and 1989 summertime convective patterns and in research mode from the Cooperative Huntsville Mesoscale Experiment (COHMEX, Williams et al., 1987). The only results presented here are for the COHMEX case of 17 June 1986, and so a brief discussion of the COHMEX project and the case in particular follows.

The input data were taken from conventional upper-air soundings that were part of the Cooperative Huntsville Meteorological Experiment (COHMEX) which took place in June and July of 1986. Redstone Arsenal, AL (RSA; see Figure 2) released a sounding each morning (1200 GMT) for forecasting purposes. An early afternoon release (1800 GMT) established a climatological data base

and provided local support for COHMEX operations. The Nashville, TN (BNA) sounding was part of the National Weather Service upper-air data network.

By 1200 UTC on 17 June a cold front associated with a low over central Ontario extended over the northern Tennessee border while a high pressure system behind the front centered over Wisconsin was advancing southward. The 1200 UTC 500 hPa analysis indicated a weak short wave moving through the Tennessee-North Carolina border area. The upper-air analyses showed that no jet streaks were present over the COHMEX area since the strongest flow aloft was near the U.S.-Canadian border. The Nashville 500 hPa wind was 10 knots while the surface wind was also 10 knots. The BNA and RSA soundings had Lifted Index values of –3°C indicating an unstable air mass over the region. Thunderstorms did not form until the front had moved through Tennessee and into Alabama.

RESULTS

Soundings from Nashville at 1200 UTC and Huntsville at 1200 and 1800 UTC were used to initialize the model for an examination of the ability of the model to simulate the boundary layer structure. Also, sensitivity to soil moisture was investigated by running the model for a dry case (25% volumetric water content) and a wet case (75%). A time series of boundary layer height for the day is shown in Figure 3, as predicted by the model from each of the six runs (wet and dry for each input sounding). One can see from the 1800 UTC initial that the six-hour forecast from the 1200 UTC runs fairly accurately simulate the short-term morning boundary layer growth period. Also, one notes the substantially shallower boundary layer for the cases which are run for higher soil moisture content, as we might expect. Finally, the model accurately predicts mixed layer collapse at the end of the day.

The model also realistically depicts the collapse of the boundary layer at the end of the day, as seen in the 1800 UTC runs. The significant differences in the h time series also imply differences in the time series for various temperatures (Figure 4), with much higher daytime and lower nighttime temperatures forecast for the dry case (not all points are shown for the dry case). In this version of the model, air temperature is assumed to change dry-adiabatically from the lowest model level (20 m) to shelter height. Shelter dew-point temperature is available by assuming that the layer of air between 2 m and 20 m has constant relative humidity. Anemometer-level wind speed (10 m) is also obtained from the lowest-model forecast wind components. In an updated version of the model now undergoing testing, these simplistic formulations will be stability-dependent, following Holtslag and de Bruin (1988). The surface energy balance is quite different for the wet case (Figure 5) and dry case (not shown), with a substantially-higher sensible heat flux for the dry case apparently causing much warmer predicted surface temperatures than for the wet case.

One of the more useful plots for forecasting would be the hourly (or more frequently, if desired) forecast soundings on the thermodynamic diagram of choice. We show only a linear plot of the boundary layer thermodynamic structure here (Figure 6). Variables such as temperature, dew-point temperature, wet-bulb temperature, potential temperature, equivalent potential temperature, etc., may be selected for plotting. For this sounding, which shows nearly saturated conditions at the boundary layer top near 1200 m, boundary layer clouds were estimated by the cloud parameterization to cover 64.4% of the sky, a factor which feeds back into the radiation parameterization. We cannot account at the present time for clouds outside of the boundary layer.

The model undergoes a smooth morning transition from stable to unstable conditions, and the evening transition is also well-simulated in all cases studied. The ability of the model to estimate minimum temperatures during conditions of nocturnal inversions, a difficult process for large-scale NWP models, was addressed by Ruscher (1988). It was determined that the explicit treatment of the stable boundary layer allowed for realistic estimations of surface temperature under these conditions.

Fuelberg et al. (1990) found the model forecast boundary layer structure to be very helpful in diagnosing the likely cause of an outbreak of convection in Tennessee on 17 June. It was found that the model realistically predicted deeper boundary layer penetration into a dry slot aloft near Nashville (as compared to Huntsville), thus allowing destabilization of the lower troposphere there. The drier air was identified on soundings upstream and in satellite retrievals, and the fact that the model could simulate realistic boundary layer growth is encouraging. The model output could include time-dependent stability indexes or could be run routinely at all upper-air sites within a given region to allow for displays of hourly surface-based lifted index (LI), for example.

CONCLUSIONS

We have only been able to present here some examples of the capabilities of a one-dimensional model of the planetary boundary layer to provide guidance for a short-range weather forecast. The model has several desirable aspects, including smooth transition across stability regimes, and incorporation of radiation, boundary layer clouds, and large-scale advection. The neglect of tropospheric cloudiness and time-dependent advection are significant problems which would preclude the use of this model under all circumstances. However, the model should perform adequately under conditions where synoptic forcing is weak to moderate and the impact of middle and high clouds is negligible.

Forecasts of maximum and minimum temperature, surface drying for agricultural applications, convective potential, mixing heights for air pollution applications, are all examples of how the model could be used in an operational setting with little modification to how it is now used in an academic environment. All of the available data would be expected to be available to the field forecaster through the data stream of their operational center, including output from large-scale NWP models which could provide the time-dependent large-scale forcing that would make the model more realistic. The model has the ability to run at higher or lower vertical resolution, allowing some additional degree of flexibility.

In spite of its shortcomings, this relatively simple treatment of boundary layer and surface-air exchanges appears to work well in providing short-term guidance for forecasting applications. We intend to pursue further improvements in the model and to begin (eventually) to run the model on a daily basis at Florida State University in operational mode to provide our local forecasters some experience with using the model. This would also be a valuable tool for teaching the importance of boundary layer and surface layer processes on the structure of the atmosphere, a very tricky problem to deal with effectively based on limited guidance from large-scale NWP models and hourly surface data.

Acknowledgements

We wish to thank Larry Mahrt, Michael Ek, Wayne Gibson (all at Oregon State University), David Stuart (at FSU) and Theodore Hoffman (now at NWS Valdez) for their guidance and assistance during the various stages of this project. Thanks also to Tom Bradshaw and Henry Fuelberg for sharing information on COHMEX.

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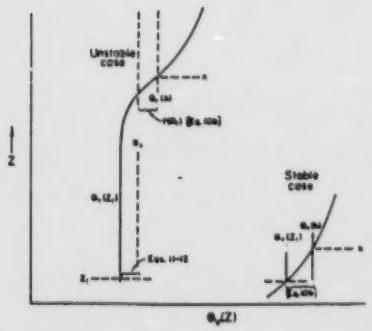

Figure 1. The determination of h for stable and unstable conditions in the PBL model (from Troen and Mahrt, 1986).

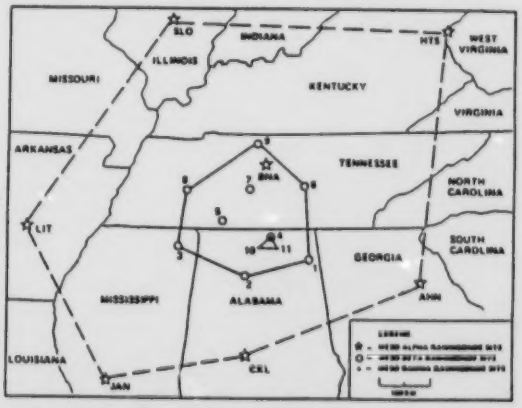

Figure 2. The COHMEX data network (from Goodman et al., 1987). RSA is at the point in northern Alabama marked "11".

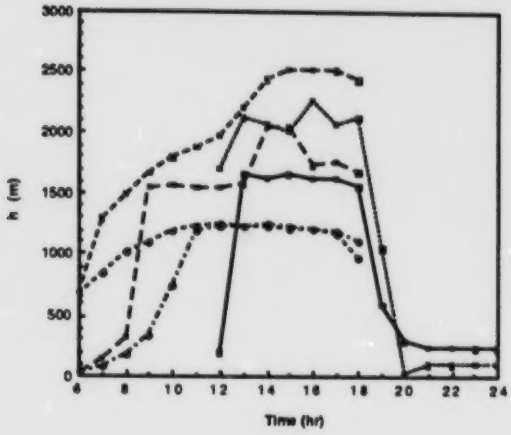

Figure 3. Time series of PBL-model diagnosed h *for six cases for 17 June 1986, during COHMEX. RSA indicates Redstone Arsenal (near Huntsville), BNA denotes Nashville. Time is local (LT = UTC–6). Curves are as follows: 1200 UTC run with dry soil for BNA, medium dash pattern with solid squares; 1200 UTC run with wet soil for BNA, short dash with solid diamonds; 1200 UTC run with dry soil for RSA, long dash with open square; 1200 UTC run with wet soil for RSA, dot-dash with solid circle; 1800 UTC with dry soil for RSA, dotted line with solid squares; 1800 UTC withwet soil for RSA, solid line with open squares.*

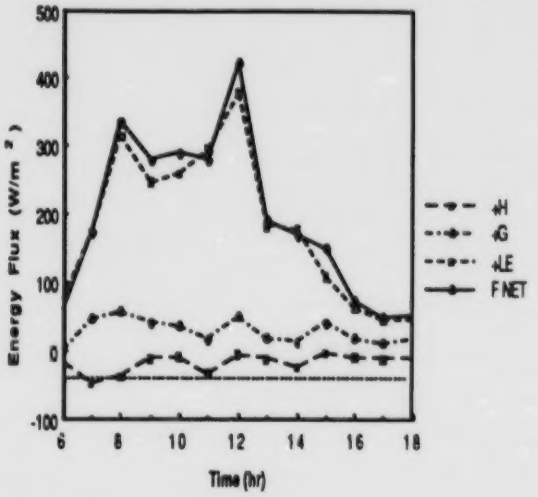

Figure 5. Time series of surface energy balance components for the model run described in Fig. 4. Sensible heat flux (+H), latent heat flux (+L), soil heat flux (+G), and net radiation (F NET) are shown.

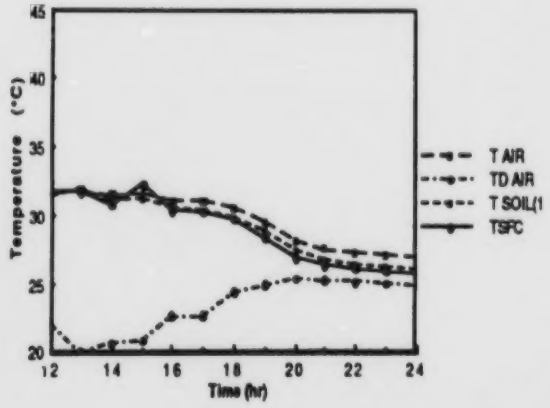

Figure 4. Time series of air temperature, dew point temperature, skin temperature, and upper soil layer temperature for the "wet" RSA 1200 UTC run. The asterisk at 1500 LT indicates the skin temperature for the corresponding dry run, at its maximum.

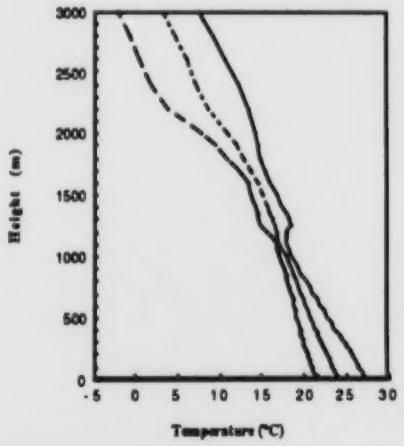

Figure 6. Predicted vertical profile of air temperature (solid), dew point temperature (dashed), and wet-bulb temperature (dotted) after 6 hours for RSA, 1200 UTC wet run. PBL top is at 1239 m and the surface layer saturation point level is 780 m.

VISUALIZATION OPTIONS AND TECHNIQUES FOR NMC'S NUMERICAL MODEL FORECASTS

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ABSTRACT

NMC's Development and Meteorological Operations Divisions have joined together to evaluate the new graphics superworkstations and associated software. Initial efforts consisted of a review of current NMC model graphics and visualization procedures and a definition of future needs. Current efforts are being focused on demonstrating the capabilities of 3-D display and its applications to model development and operational forecasting. Future efforts would be directed towards increasing user interactivity, and increasing data access speed.

RÉsumÉ

Les divisions de développement et des opérations météorologiques du NMC se sont jointes afin d'évaluer les nouvelles super-stations de travail graphiques et le logociel associé. Au début les efforts ont été mis à revoir les modèles graphiques actuels et les procédures de visualisation employés à NMC. Maintenant nos efforts se portent à démontrer les capacités de l'affichage 3-D et ses applications à la prévision opérationnelle et au développement des modèles. Dans le futur, nous nous concentrerons sur une augmentation de l'interaction avec l'usager et de la rapidité à l'accès aux données.

1. INTRODUCTION

In order to keep pace with the rapid technological advances underway in the interactive workstation arena, the National Weather Service's National Meteorological Center (NMC) has begun a program to review the various display capabilities offered by some of the latest hardware and software platforms. NMC's Development and Meteorological Operations Divisions have joined together to evaluate the new workstations and associated software. The effort involves special postprocessing of NMC's numerical forecasts from the operational Regional Analysis and Forecast System (RAFS, Hoke et.al., 1989), the Medium Range Forecast Model (MRF, Sela, 1982) as well as the experimental ETA coordinate model (Mesinger et.al., 1987). The model forecast grids are then processed into various three-dimensional displays to take advantage of the new visualization capabilities.

2. BACKGROUND AND REQUIREMENTS

The initial efforts consisted of a review of current Meteorological Operations Division (MOD) and Development Division (DD) model graphics and visualization procedures and a definition of future needs. MOD currently has access to AFOS (Automation of Field Operations and Services), VDUC (VAS Data Utilization Center, Hostek and Siebers, 1987) and a variety of hardcopy output identical to those distributed to field forecast offices. DD researchers and programmers are limited almost exclusively to batch-submitted programs which produce copious amounts of hardcopy output. A VDUC workstation is also available in DD but is used primarily for graphics development. While new graphics products have become available to both divisions in recent years (Plummer, 1989), no true, interactive preview capabilities exist at this time. However, GEMPAK (General Meteorological Software Package, desJardins and Petersen, 1983) will be established in both MOD and DD by the end of 1990.

While these products and procedures have provided an acceptable level of quality in the past, the needs of the future will require faster and more complete interactive perusal and editing of gridded and observed data. The demands of operations insist on timeliness, clarity and ease of workstation use. Animation capability (sequential display of consecutive analyzed or forecast atmospheric states) is also necessary for complete user comprehension of model forecast processes. Fast local processing of basic state data would also be a necessity. The requirements of research

scientists are similar to those of operations with less emphasis on timeliness and more on generalized data display and local processing.

Based on these needs, an initiative was generated with the following list of hardware and software requirements:

- Graphics Workstation subsystem / accelerator consisting of
  - 2 64-bit processors
  - 128 Mbytes CPU Memory
  - 5+ Mflops Floating-point performance
  - 3 Gbytes Local Storage
  - 19" 1280x1024 Color Monitor
  - 16.7M Available/Displayable Colors
  - RISC Architecture
  - TCP/IP Ethernet Communications
  - 8 Frames per Second Animation
  - Upgradable
- Unix-based Operating System
  - Must include AVS Software
  - Must accept 100K+ Grid Point Data
  - Must accept PHIGS+
  - Must accept CGM
  - Must accept Cray Source Code
  - Fortran and C Compilers

These requirements result in an estimated cost of $80-100K per workstation. While this expense is large for the average forecast office at this time, hardware prices should drop considerably in the next 5 years making graphics superworkstations affordable to most within this decade.

3. CURRENT DEMONSTRATIONS

The most recent efforts are being focused on demonstrating the capabilities of 3/4-D display and its utility at NMC. Of greatest interest to NMC, of course, is the new technology's applicability to operational forecasting and model development. To fill these requirements, we posed the question: Which new workstations provide the most useful capabilities in the most cost efficient manner? Several workstations were able to display three dimensional gridded data. However, two in particular contained earth-system software suitable to address NMC's needs. These were the Stardent GS1000 series and the Silicon Graphics IRIS series, and are the machines used to generate the images displayed in this poster presentation. Software designed for earth science applications has been developed on a Stardent GS1000 at the Space Science and Engineering Center (SSEC) of the University of Wisconsin-Madison (Hibbard and Santek, 1989) and also on a Personal IRIS at Dynamic Graphics, Inc. The Application Visualization Software (AVS) used by the applications programmers at SSEC and Dynamic Graphics was developed by the respective hardware manufacturers.

Data preparation and display for these machines were quite simple. NGM 50mb post processed gridded fields were written to tape and downloaded onto the IRIS via a microVAX link. The three dimensional grids were then processed into solid, iso-valued surfaces (similar to contouring) by the AVS software. The surfaces were then displayed while an interactive interface allowed the user to rotate and slice through different sections of the data. Various outer surfaces could be made transparent, revealing the interior structure of the field. Processing and display of the MRF fields on the Stardent workstation was equally simple. Several of these capabilities are shown for both the NGM and MRF in this poster presentation.

4. FUTURE CONSIDERATIONS

Once a graphics superworkstation had been acquired, efforts would probably be directed towards the timeliness of data availability, increasing local storage and computational power, and increasing the data transmission speed from the supercomputer to the workstation. Ease of interactive access would continue to be of paramount importance in the future.

5. ACKNOWLEDGEMENTS

We would like to thank Dennis Smith of Dynamic Graphics, Inc. in Bethesda, MD as well as Bruce Bennett and Norman Siegel of Stardent Computer, Inc. in Reston, VA for providing the hardware, software and general assistance necessary for our demonstration.

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SPINUP POTENTIAL

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RESUME

Une variante de l'approche classique à la modelisation, destinée à faciliter la sélection du meilleur modèle de prévision, est décrite ici.

Plusieurs principes physiques interviennent dans cette approche. On suppose que le frottement est un moteur important à l'échelle synoptique; on suppose aussi un spectre universel d'ondes gravitationnelles à partir desquelles on estime les transferts et les transformations d'énergie. On exploite la bidimensionalité de la théorie du "spinup" d'un fluide avec le temps local du "spinup" géostrophique utilisé dans la solution d'un système de vibrations amorties.

La terme qui en résulte, le potentiel de "spinup", est étroitement relié à la vitesse verticale au niveau moyen de la troposphère au temps de vérification.

INTRODUCTION

The conventional modelling approach, that of integrating the Navier-Stokes equations, has been relatively successful in providing the operational meteorologist with the required fields to forecast weather at intermediate time and space scales.

Mid tropospheric level vertical velocity remains one of the most poorly forecast fields. While the forecast isobaric pattern may be excellent according to some objective criterion such as the "S1" score, the associated vertical velocities as verified by cloud and precipitation patterns are frequently poor.

That fact was one of the prime motivations in the search for the alternate modelling approach described in this abstract. The initial motivation, however, was the operational need to decide which of a number of given models presenting different solutions was likely to be the best one given a specific synoptic situation. There is little objective guidance upon which to base such subjective assessment. The nature of the problem dictates that such guidance should not employ, nor be derived from, a conventional integration of the Navier-Stokes equations. At the same time, in order to be useful, an alternate solution (model) would need to be available contemporaneously with the operational models.

Models are *partial* representations of objective reality. Current operational models attempt to reproduce reality in *toto caelo*, limiting the possibility of controlled experimentation by their complexity. Simpler models, concentrating on certain scales or aspects, could provide the meteorologist with the opportunity of exploring atmospheric dynamics from a focussed perspective.

BACKGROUND

Batchelor [1953] suggested that the gradient Richardson number, defined as the ratio of representative density and velocity gradients over some finite depth of the atmosphere, is the only parameter necessary for dynamic similarity of flow fields described by the inviscid adiabatic equations describing incompressible motion. Turbulence is implicitly included. Those factors which ensure dynamic similarity between two flow fields, by definition ensure the that the ratio of corresponding forces between the fields is the same. That implies that the energetics of the two flow fields are similar.

Transformation of the horizontal equation of motion to nondimensional form results in the appearance of three nondimensional ratios, one of which is the Froude number, with dimensions the inverse of the gradient Richardson number. If one is focussing on the gradient Richardson number as an "integrating" factor then the expectation would be that the ratio of inertial and gravitational forces would play determining roles in the dynamics. The hydrostatic assumption must be a key assumption.

If the characteristic length scale is large compared to the representative wind then the Rossby number is small and the Coriolus effect is important. With the Reynolds number comparable to the Rossby number, the vertical shear term becomes the dominant forcing function.

The gradient Richardson number is usually employed in attempting to define the likelihood of clear air turbulence, sometimes identified with "internal friction" or the dissipation of kinetic energy in the free atmosphere. There are various estimates of the importance of such internal friction, ranging from insignificant on the synoptic scale to those of Kung [1966], which would imply that the mean rate of dissipation of kinetic energy is the same order of magnitude as that in the atmospheric boundary layer.

"There is therefore an *a priori* possibility that small-scale motions, which are not the focus of our interest, may yet influence the large scale motions." Pedlosky [1979](1.4.5)

Pedlosky discusses the probable relative importance of frictional forces compared to the Coriolus acceleration and the pressure gradient, concluding that "frictional forces are weak in comparison with nonlinear relative acceleration. Nevertheless friction, and the dissipation of mechanical energy it implies, cannot be ignored.... <u>In addition, the driving force itself may be frictional, as in the case of the wind driven oceanic circulation."(4.1)</u> *.

THEORETICAL APPROACH

An underlying hypothesis in the work outlined herein is that small-scale "frictional" driving <u>largely</u> determines synoptic scale events on time scales of the order of 1 to 3 days. If this

* Underlining not in original

is true, then modelling based on that assumption must successfully incorporate "up-scale" energetics.

Van Zandt [1982] proposes an alternative to the Gage [1979] suggestion of a mesoscale energy spectrum produced by two-dimensional turbulence, suggesting instead a wave-based model of the mesoscale variance spectra, similar to the Garrett-Munk oceanic theory. The spectrum of horizontal winds between wavelengths of 10 and 1000km is fit relatively well by a slope of -2.

Roach [1970] describes the experimental and theoretical development of the role of gravity waves and Kevin-Helmholtz instability in producing or maintaining internal friction. He derives, from energy considerations, an expression for the rate of turbulent energy flux in a turbulent shear layer in terms of the local Richardson number.

Gravity waves occur almost universally in stably stratified flows, transporting momentum and energy and exchanging it with the mean flow. Linear perturbation theory results in the wave dispersion equation. If possible values of the frequency are limited to the hydrostatic range then the Coriolus terms are negligible. The assumption is made that in any given region of space there is a dominant wavenumber about which is centered a wave group, and that wave energy is (primarily) associated with this length. The length is identified with the Prandtl-von Karman mixing length, expressible in terms of the Richardson number given constancy assumptions about the local flux of turbulent energy. Local energy divergence is then calculated, taking into account results of the linear theory of wave breaking. A local turbulence-induced vertical velocity results from the horizontal affects.

In order to proceed to a forecast field without going through the usual integration of partial differential equations the following assumptions are made:

i. There is an equivalent internal Ekman layer associated with the vertical velocity.

ii.The atmosphere moves (locally) to the spun-up (or spun-down) state in a local geostrophic spinup time. The local balanced state to which the atmosphere is moving is a nodal (i.e. maximum or minimum) energetic state.

iii.The governing equation is that of a damped vibrating system and the solution is the response of the system to a single square wave.

iv.There are no internal non-divergent discs.

In order to calculate the spinup time assumptions have to be made about the initial boundary layer. A crude analog to the surface boundary layer equation is used with a local roughness length.

RESULTS

The model is currently being run by the author on operational shifts and compared with the operational models available. In spite of the many assumptions and approximations which in them-

selves have to be judged dubious, this novel approach has proven to be excellent in suggesting areas of mid-tropospheric vertical velocity at 36 hours, areas frequently absent or not adequately depicted on the operational models .

The output is called "spinup potential" and expressed in dimensions of velocity .

The accompanying charts are typical of the results achieved. Figures 1 and 2 are the 36 hour forecasts of spinup potential and Finite Element Model isobaric-thickness pattern. The positive areas and "Highs" on figure 1 correspond to "upward" vertical velocity. Figures 3 and 4 are the 500mb chart and cloud photograph for the verifying time, included to help identify the most probable areas of vertical velocity maxima and minima.

Figure 1 Valid Time 00Z/90/02/05

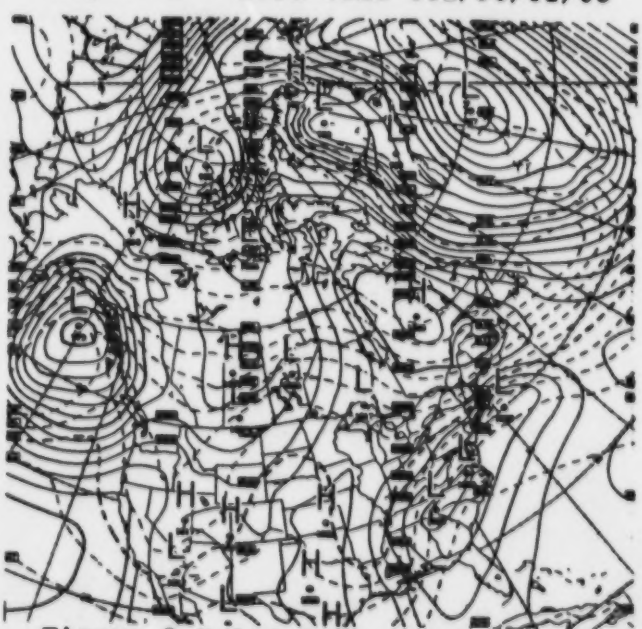

Figure 2 Valid Time 00Z/90/02/05

CONCLUSIONS:

In most instances the sign of the spinup potential is the same as the verifying vertical velocity. The reliability of the absolute value of maxima or minima is poor. Improvement of the latter could probably be achieved by incorporating the local characteristic length scale and wind as an expected reliability check, and by improving the initial effective boundary layer depth. There are several other parameters which can be "toggled" and considerable room for experimentation.

The results are promising enough to continue exploring this avenue from both the theoretical and applied perspective. Forecast parameters can be incorporated. At present a single height assumption is made for the equivalent internal Ekman layer. A variable height might prove superior. If related directly to the vertical velocity the spinup potential might serve as a forcing function in a simple baroclinic model.

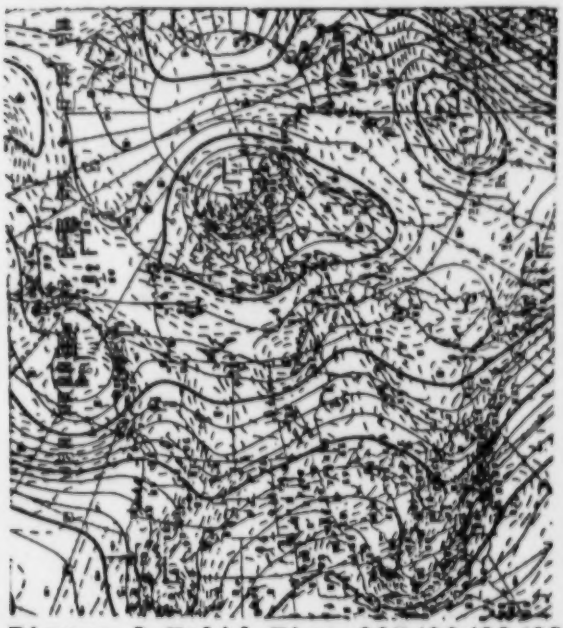

Figure 3 Valid Time 00Z/90/02/05

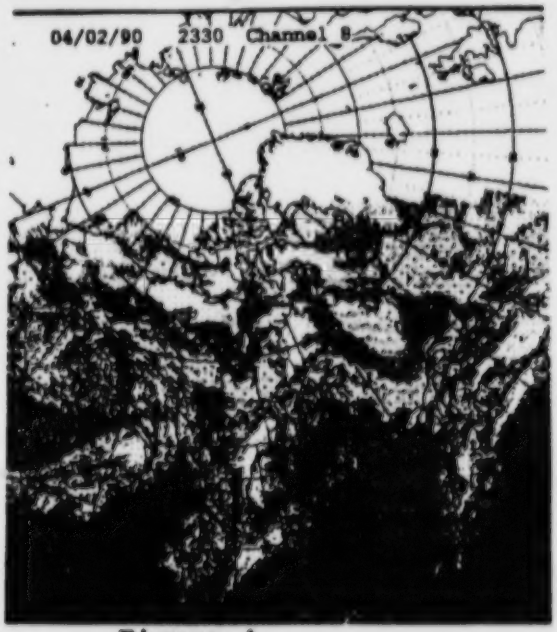

Figure 4

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THE INFLUENCE OF BARRIER JETS ON LOCAL SNOWFALL DISTRIBUTIONS

by

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ABSTRACT

The influence of blocked, low-level, cold air on the mesocale distribution of snowfall is presented. An existing conceptual model for cold-air damming in northeast Colorado is presented that requires a quasi-stationary, surface-convergence line; heavy snow is expected near this line as moist air is displaced upward over the cold air. Data collected during a winter-weather experiment in January 1989 are presented that suggest the surface-convergence line is not required and only represents one variation of this blocking phenomenon. It is suggested that the two extremes are (1) a nearly stagnant, local, cold pool with a stationary leading edge that has a characteristic density current structure, and (2) a well developed barrier jet with no stationary surface boundary and a steeply sloped interface.

RÉSUMÉ

L'influence d'air froid bloqué à bas niveaux sur la distribution à méso-échelle des quantités de neige est examinée. Nous présentons le modèle conceptuel existant pour cet effet de barrage sur le nord-est du Colorado nécessitant la présence d'une ligne de convergence de surface quasi-stationnaire; la neige forte est attendue près de cette ligne alors que l'air humide est soulevée sur l'air froid. Un cas de janvier 1989 suggère que cette ligne de convergence n'est pas nécessaire et ne représente qu'une variation de ce phénomène de blocage. Il est suggéré que les deux cas extrêmes sont (1) une masse d'air froid local et quasi-stagnante avec une structure de densité particulière, et (2), un jet bloquant bien développé avec aucune frontière de surface stationnaire et une interface avec pente abrupte.

INTRODUCTION

It is well known that local terrain can have a dramatic influence on flow patterns and precipitation, often to such a degree that it overshadows the largescale circulation. One such influence occurs when stably stratified air is forced against a mountain barrier. Whether the air is able to cross the barrier or not is a function of the mountain height, static stability, and wind speed. Schwerdtfeger (1975) was the first to describe this blocking effect in a study of low-level winds along the Brooks Range in northern Alaska. He explained that as a layer of cold air is forced up a slope, the upper surface of the cold air will reflect that slope. Then, through a simple hydrostatic analysis, it can be argued that a local pressure gradient (directed away from the terrain) is established. The geostrophic response to this gradient is a flow directed parallel to the terrain; for the northern hemisphere, in the direction of the flow, the higher terrain is on the right.

Flow patterns of this type have been documented along the western slopes of the Sierra Nevada Mountains (Parrish, 1982) and the eastern slopes of the Appalachians (Bosart, 1975 and Richwien, 1980). The dramatic influence of this blocked, low-level, cold air on precipitation was shown by Forbes et al. (1987) for an ice storm east of the Appalachians.

LOCAL PROBLEM

The synoptic setup for a classic upslope snowstorm in northeast Colorado has a cold front extending from southern Colorado northeastward into the upper Midwest. The snowstorm typically occurs in the post-frontal environment with northeast or upslope flow in the boundary layer. Cold-air blocking or damming in this post-frontal flow was first identified by local meteorologists in the Boulder and Denver communities trying to explain the dramatic, small-scale, storm-to-storm variations in snowfall. A real-time experiment conducted by PROFS (Program for Regional Observing and Forecasting Services) resulted in the first conceptual model addressing this phenomenon (Schultz, et al., 1985); their schematic is shown in Fig. 1(a). The salient features of the model are (1) a cold surge moving southward along the eastern foothills of the Rocky Mountains, (2) a moist, southeasterly low-level flow into southeastern Colorado, and (3) a quasi-stationary convergence line where the two flows meet, with a strong enhancement of snowfall just to the west of the convergence line or meso-front.

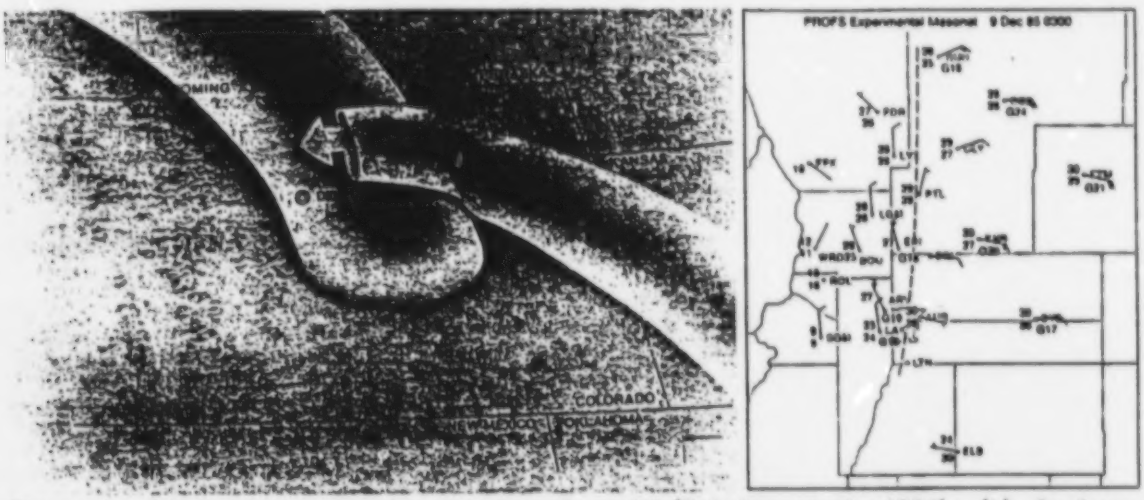

Figure 1. (a) Cold-air damming conceptual model (Schultz, et al., 1985). (b) Surface mesonet data from a cold-air damming episode (Dunn, 1987); heavy snow was occurring to the west of the convergence line.

Dunn (1987) was able to document such a storm in a detailed case study utilizing many of the special data sets available in the local Denver area (namely, a surface meso-network, wind profiler, and wind tower). He raised the important question about formation; whether the cold air was formed in situ or whether it moved in from the north in association with a synoptic-scale front. He felt that in the case he presented there was considerable local development. A meso-analysis from his case for a time of heavy snow in Denver is presented in Fig. 1(b). Additional analyses by Wesley and Pielke (1989) addressed the issue of variations in moisture and depth of cold air in producing variations in the positioning of heavy snow west of the convergence line. The common feature in each of these studies and in the PROFS model is the existence of a quasi-stationary surface-convergence line. This feature is similar to the coastal front east of the Applachians. Also similar among these cases is the eastward displacement of the influence of the terrain on the production of snow. This model of cold-air damming has been incorporated into the operational functions at the local NWS Forecast Office; when a surface-convergence line forms, or is anticipated to form, the forecasted area of heavy snowfall is adjusted eastward to account for this low-level convergence.

A recent field program conducted by the Forecast Systems Laboratory has provided additional clues on the effects of blocked cold air on local snowfall distributions in

northeast Colorado; these data will now be presented and then modifications to the existing conceptual model will be proposed.

CASE STUDY

These data were collected during a winter-weather experiment in which two supplemental sounding sites were placed between Denver (DEN) and Dodge City (DDC); a transect extending southeastward from Denver approximately 500 km. It was hoped that sampling along this transect at 3-h intervals would provide some additional insight into the structure of a northeast Colorado snowstorm; such a storm occurred on 28 January 1989. At the height of the storm, there was a closed mid-tropospheric circulation southwest of Denver with significant upper-level dynamics over northeast Colorado. The geostrophic flow was out of the east through a deep layer, which is an upslope component and a favored condition for heavy snow. Due to length, further discussion concerning the synoptic-scale setting will be saved for the presentation.

The mesoscale discussion will focus on a northerly surge that moved through the local Denver area prior to the start of the snowfall. At the Denver observing site, there was a reported wind shift from 160 degrees to 320 degrees at 0045 UTC, 28 January 1989; snow began to fall at 0445 UTC with a dramatic increase in wind speed at 0450 UTC. Over the next several hours winds continued to increase with a sustained wind of 23 kt at 0750 UTC and gusts to 40 kt slightly later. This cold surge was remarkably sharp as it passed through the local observing network, as is typical of many frontal passages along the Front Range. A time series of winds from the Denver profiler shows the deepening with time of this surge (see Fig. 2). (Note: The winds greater than 50 kt are most likely erroneous and contaminated by precipitation.) By 0600 UTC the surge had deepened to about 700 mb, which is near mountain top for the Rockies in this area. The observed strong northerly component below 700 mb is not in agreement with the analyzed geostrophic flow (not shown). This suggests that there is a barrier jet forced by blocking of the stably stratified low-level flow.

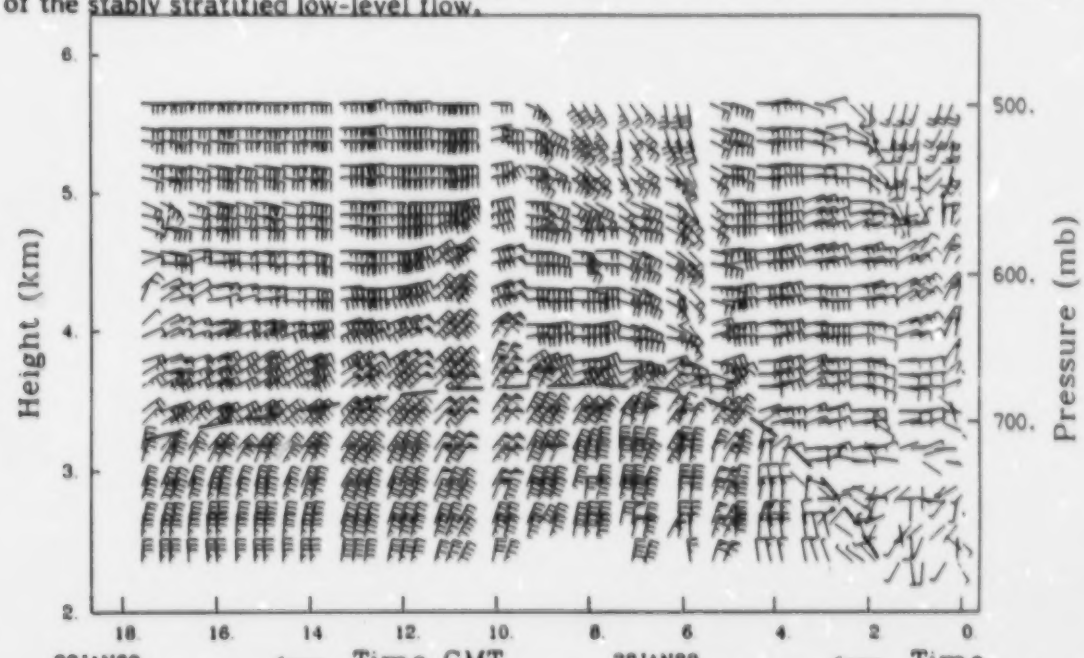

Figure 2. Time series of winds from the Denver profiler for the period from 0000 UTC to 1800 UTC, 28 January 1989. Flags represent 25 m/s; barbs represent 5 m/s; and half barbs represent 2.5 m/s.

Snow continued to fall all morning with the bulk of the snowfall occurring in the Denver area between 1200 UTC and 1800 UTC. Total snowfalls ranged from several cm 100 km east of Denver to over 50 cm northwest of Denver. The distribution of snowfall showed moderate amounts extending well east of the sharp rise in terrain to the west of Denver. Thus, it displayed the eastward shift of the terrain effect characteristic of cold-air damming cases, yet it did not show the expected secondary maximum east of Denver.

An analysis of the sounding data collected along the transect from DEN to DDC at 1200 UTC 28 January is shown in Fig. 3. A very stable boundary layer extends across the entire cross section. The surface front has passed Denver and Flagler (FLG), with Tribune (TRI) and Dodge City still on the warm side. The lower potential temperatures toward the east are explained by the sloping terrain. A frontal zone is seen emerging from the stable boundary layer near Tribune reaching 600 mb at Flagler and Denver. Within this frontal zone there is a strong cold-advection wind profile at Tribune between 850 mb and 700 mb. The barrier jet can be seen in the Denver sounding where the wind speed is nearly constant below 730 mb and increases from the northeast above. The isentropes below 700 mb slope away from the terrain identifying the layer of blocked, cold air.

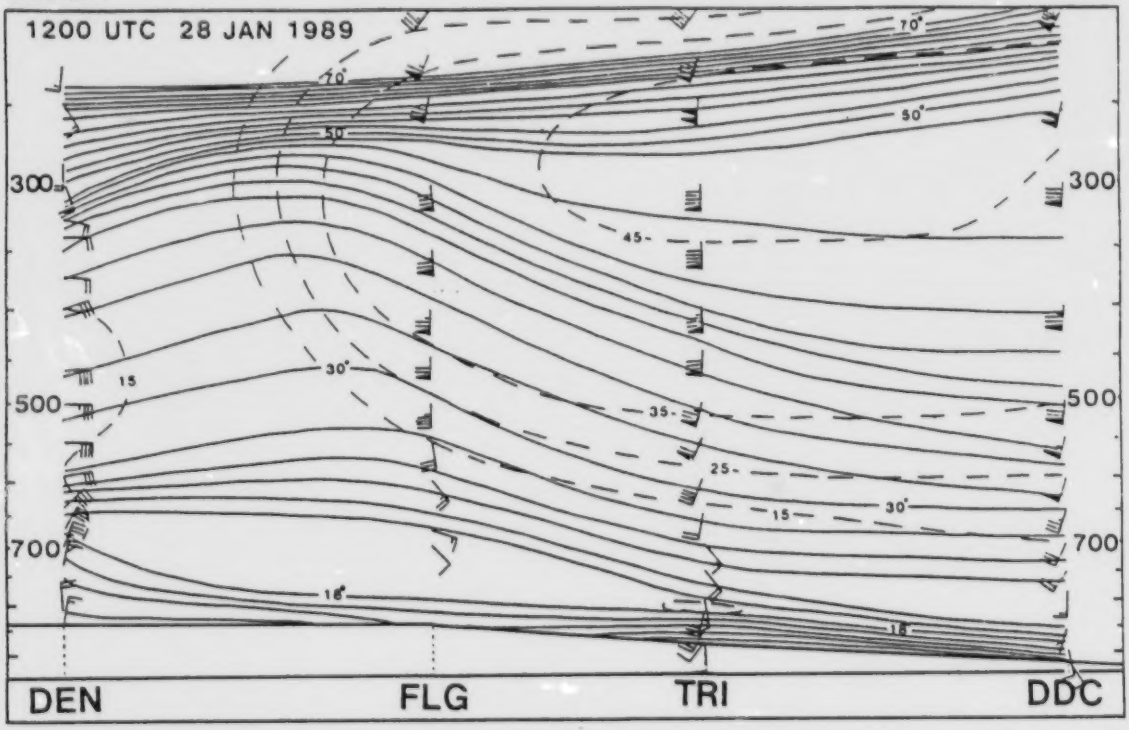

Figure 3. Vertical cross section along the DEN to DDC transect for 1200 UTC 28 January. Isentropes in °C and isotachs in m/s.

An inspection of the visible satellite imagery suggests the precipitation was convective in nature throughout the storm. Soundings taken during the storm (not shown) show a convectively-unstable layer moving upslope over northeast Colorado. Apparently critical to the effectiveness of this upslope component is the barrier jet. The effect of the jet is to exagerate the slope of eastern Colorado. This can be seen by looking at the slope of the 18°C isentrope between Flagler and Denver in Fig. 3. The change in pressure along the isentrope is over 100 mb; yet, the difference in surface pressure

between Denver and Flagler is only 10 mb. Since the barrier flow is terrain locked there is no east-west phase velocity for the feature, and the 18°C isentrope changes little in subsequent analyses (not shown), it can be inferred that any westward-moving parcels will experience isentropic upglide under adiabatic conditions. Additionally, the isentropes represent a lower bound since any latent-heat release forces transport to higher isentropic surfaces. In fact, the air at the top of the stable layer in the Denver sounding has the same equivalent potential temperature as the maximum equivalent potential temperature in the lower-levels of the Flagler sounding (not shown).

A regional surface plot valid at the time of heavy snow is shown in Fig. 4. From this analysis it can be seen that a second difference between this case and the classic cold-air damming conceptual model discussed earlier is that there is not a quasi-stationary, local, surface-convergence zone. The surface frontal boundary continued to advance southward over all of eastern Colorado during the event. Thus, it seems that some of the features associated with the conceptual model for cold-air damming were present while others were not. The following section will address these differences and propose modifications to the conceptual model.

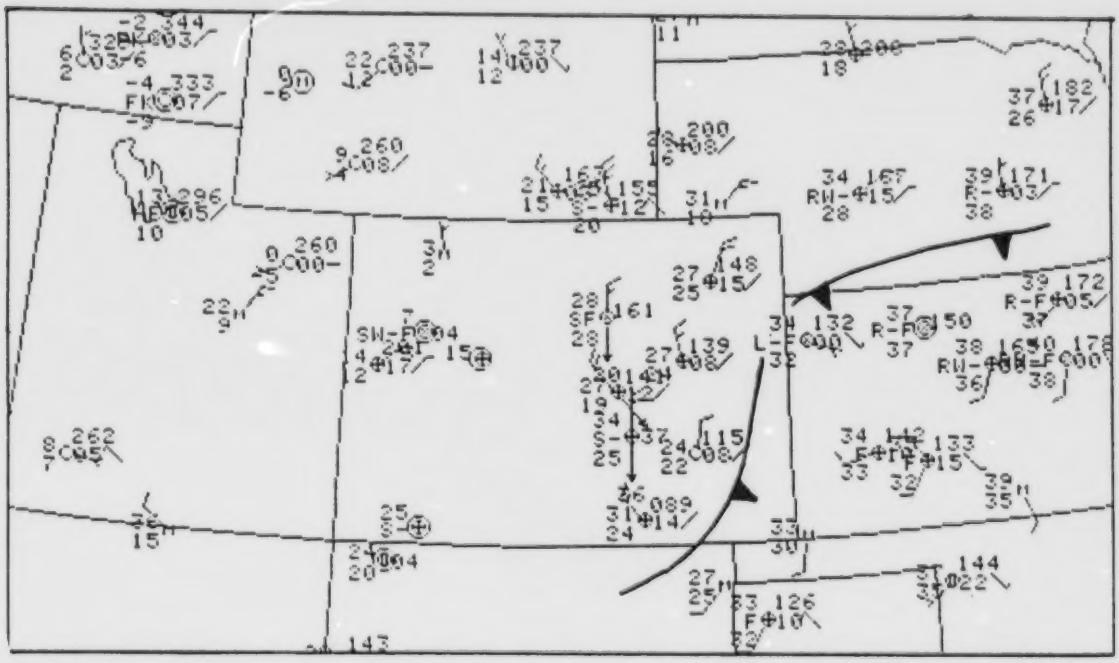

Figure 4. Regional surface plot showing position of cold front. Station plots are conventional.

DISCUSSION

It is apparent from this case study that the surface-convergence line is not necessary for blocked, cold air to have a dramatic influence on the local snowfall distribution. The leading edges of cold surges along the eastern Rockies are known to be very sharp, with very steep interfaces, and look like density currents (e.g., Shapiro, et al., 1985). It is likely that the cold air at the surface-convergence line is similarly shaped and explains the observation that the snowfall enhancement is located very near to the surface boundary. If the cold pool were totally stagnant, the upper surface of the cold air would be flat away from the surface boundary, i.e., no barrier jet. This configuration is most likely when the upslope flow is weak and is possibly dependent upon local generation. On the other hand, when the easterly geostrophic flow is strong the

upper surface of the cold air will be steeply sloped away from the terrain with the development of a strong barrier jet. In this case the leading edge of the cold air will also look like a density current but will continue to move southward out of the local area. The focus of the enhanced snowfall is then along the steeply sloped cold air to the east of the higher terrain.

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STRATUS SURGES ALONG THE BRITISH COLUMBIA COAST: THE RESULT OF A MESOSCALE PROCESS

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Abstract

During the summer, a narrow tongue of stratus will often surge northward along the west coast of North America for 1000 km or more. This stratus motion is difficult to explain from a synoptic scale perspective. Characteristics of a typical alongshore stratus surge are described. Gravity currents and Kelvin waves are two mesocale processes which may explain the behaviour of stratus surges. Details of these processes are discussed and the case of Sept. 3. 1988 is used to illustrate a west coast stratus surge. Similar surges may occur along other mountainous coastlines such as the Alaskan North Slope.

Durant l'été, une étroite langue de stratus remonte souvent la côte ouest de l'Amérique du Nord sur plus de 1000 km. Cette remonteé ou pousseé de stratus s'explique mal si on ne considère que l'échelle synoptique. Les caractéristiques d'une remonteé typique de stratus sont décrites. Deux processus de la méso-échelle, les courants de gravité et les ondes de Kelvin, expliqueraient le comportement des pousseés de stratus. Les détails de ces processus sont discutés et le cas du 3 septembre 1988 est utilise pour illustrer une remonteé de stratus sur la côte ouest. Il est possible que des poussees de stratus se produisent le long d'autres côtes montagneuses telles que la cote nord de l'Alaska.

INTRODUCTION

A light offshore flow is often a prescription for sunshine and above normal temperatures along the west coast of Vancouver Island. These pleasant conditions however can come to an abrupt end as a rapidly moving fog bank invades from the south and shrouds the coast for days. In fact, during the summer months, it is not uncommon for a narrow but continuous band of fog or stratus to surge northward for 1000 kilometres or more along the west coasts of the United States and British Columbia.

These alongshore stratus surges have a major impact on both the aviation and marine communities. The accompanying low ceilings and dense fog essentially paralyze air travel. The fog has also contributed to collisions between ships at the entrance of Juan de Fuca Strait; right in the lane used by oil super tankers. Strong winds also accompany the stratus surges and often attain gale force strengths near the headlands of Vancouver Island. An accurate forecast of this event therefore can be of great value.

Many of the alongshore stratus surges observed on the B. C. coast share the following characteristics:

- The stratus surge is usually preceded by a warm northerly or northeasterly offshore flow that is maintained by a weak low pressure trough just off the coast.
- Initially a large area of stratus is present just off the Oregon coast and is easily detected by visual satellite imagery.
- A narrow tongue of stratus hugs the mountainous coastline as it moves northward.

-As the leading edge of the stratus reaches a coastal observing site the winds will often shift from a light northerly to a stronger southerly flow.
-As the stratus arrives, an abrupt temperature drop is often observed.
-A fairly sudden jump in pressure occurs near the leading edge of the stratus surge.
-A long and very narrow high pressure ridge forms along the coast and appears to follow the leading edge of the stratus.
-Observed surface winds at coastal sites are usually stronger and more persistant than normal.

When viewed on the synoptic scale, the behaviour of this type of stratus surge can be puzzling. The observed northward motion is often too rapid to be explained by a synoptic scale geostrophic advection process. One must ask, "What process is actually propelling the stratus northward?" Two different processes have been employed to explain these alongshore stratus surges: gravity currents and Kelvin waves.

GRAVITY CURRENTS

Clifford Mass and Mark Albright have used the concept of a topographically trapped gravity current to explain the alongshore stratus surges observed on the west coast (Mass and Albright 1987). Their explanation of this process involves the following stages:
-Initially a northeasterly flow transports warm dry subsiding air from the interior over the ocean, forcing the cold moist marine stratum offshore.
-Later, the flow over a portion of the coast will reverse and cause the dense marine layer to move onshore and deepen as it piles up against the north-south barrier of the coast mountains.
-The density contrast between the warm air from the interior and the much colder marine stratum will produce a pressure difference along the narrow boundary which separates these two regimes.
-This mesoscale pressure gradient will cause the marine stratum to surge northward. It is the added weight of this shallow but dense marine layer which propels the stratus up the coast. This also explains the formation of the narrow high pressure ridge observed during these events.
-The Coriolis force will deflect the northward moving stratum against the coastal mountains and prevent the layer from spreading out to sea. As a consequence a narrow current of stratus will hug the coast mountains as it progresses northward up the coast.
-Abrupt pressure rises and temperature falls would occur at the density front at the leading edge of the gravity current.

The following empirical formula relates the velocity of a gravity current to the pressure jump which occurs at the head of the surge (Seitter and Muench 1985).

$$V = 0.79\sqrt{\Delta P/\rho} \qquad (1)$$

Where: V is the velocity of the gravity current.
ΔP is the pressure jump - a 2 hour average of the pressure immediately following the surge minus the pressure just before the surge arrives.
ρ is the density of the warm air.

This formula works quite well as will be shown in case for Sept. 3, 1988. This gravity current model accounts for many of the observed characteristics of alongshore stratus surges and suggests the process is in many ways similar to a stream of water being redirected by a roadside curb. In order to sustain a gravity current however, one requires a large reservoir of cold stratified

air which is being directed toward the coast, usually by a synoptic scale circulation. Some have argued that the reservoir of cold air is insufficient and the synoptic forcing is too weak to maintain the very long surges which are often observed (Reason 1989).

KELVIN WAVES

The Kelvin wave is another process which explains many of the characteristics of alongshore stratus surges but does not require this large reservoir of cold air. In contrast to the gravity current which actually delivers the cold air, a Kelvin wave propogates along the inversion formed between the marine stratum and the subsiding warm air aloft. A Kelvin wave also requires a mountain boundary which is higher than the inversion, as well as some force which will cause the marine stratum move toward a portion of this boundary and converge and deepen. The vertical displacement caused by this deepening will then ripple along the inversion as a gravity wave. The winds induced by this wave will be deflected by the Coriolis force. As a consequence, the energy of this wave will be confined close to the boundary, which in the northern hemisphere lies to the right of the moving wave. As a Kelvin wave travels along the coast, the surface pressure will peak at the crest of the wave and drop to a minimum at the trough. On the west coast, the winds will shift from a northerly to a southerly direction as the trough passes. This reversal in flow however does not imply a sudden temperature drop or an invasion of stratus. The deepening of the marine inversion however could lead to stratus formation because mixing through a deeper layer may allow air to rise above the condensation level.

Since topographically trapped gravity currents enhance inversions along the mountain barrier, they provide an ideal environment for Kelvin waves. By examining linear and non-linear terms of the shallow water equations, it has been argued that Kelvin waves can not only propagate along gravity currents but even overtake them (Reason 1989). As a consequence, an alongshore stratus surge may start off as a gravity current and end up as a Kelvin wave.

The relative importance of gravity currents and Kelvin waves continues to be a subject of active debate in the research community. Even though this debate is not totally resolved, these mesoscale processes offer considerable insight into the behaviour of alongshore stratus surges. As a consequence, the ability to predict such events has been greatly improved.

THE ALONGSHORE SURGE OF SEPTEMBER 3, 1988

On Sept. 2, 1988 the main synoptic feature at the surface was an inverted trough which extended from Southern California to Western Oregon. This trough was flanked by two high pressure ridges. The one extending southward from the Queen Charlotte Islands gradually weakened during the period while the other ridge, along the B. C. Alberta border gradually shifted eastward and strengthened during the next two days. A detailed analysis at 18Z on the 2nd also revealed a weak 1013 millibar low 150 kilometres west of the mouth of the Columbia River with a trough extending southwestward and a narrow high pressure ridge inching northward along the Oregon coast (Fig. 2). This pattern produced a moderate to strong northerly flow off the Vancouver Island coast which gradually eased as the ridge over the Queen Charlottes weakened. A light southerly flow was present along the Oregon Coast on the afternoon of the 2nd while a light northerly or northeasterly flow prevailed along the Washington coast.

Animation of visual GOES satellite imagery for Sept. 1st and 2nd revealed that a 120km wide bank of stratus progressed northward along the Oregon coast and then stalled when its leading edge reached the mouth of the Columbia (Figure 1). Although a gravity current or a Kelvin wave may have propelled the stratus up the Oregon coast, such a process ceased when this cloud stalled. Other stratus surges have also paused in this very location and may be related to the major gaps in the coastal mountains which exist between the mouth of the Columbia River and the Olympic Mountains over Northwestern Washington. While this behaviour is intriguing it is not the topic of this paper. The contribution of this initial surge was to position a source of stratus within striking distance of the B.C. coast.

With the stratus stalled well south of Vancouver Island, one might conclude that it was not a potential forecast problem. On the evening of the 2nd however stations along the Washington coast began to indicate that the stratus was indeed progressing northward. At 05Z on the 3rd, Destruction Island (mid way up the Washington coast) reported an abrupt wind shift from a northeasterly to a southerly, a sudden pressure rise and an 8 C temperature drop. A similar pattern occurred at Tatoosh Island (on the Washington side of the Juan de Fuca Strait) at 07Z and at Nitinat (on the Canadian side of the Juan de Fuca Strait) by 9:24Z. Because the invasion of the stratus was associated with abrupt temperature drops and pressure rises, the alongshore surge at this stage appeared to exhibit the characteristics of a gravity current. The following estimates of the gravity current speeds were obtained by placing the pressure data for each station into equation (1).

Station	Destruction Island	Tatoosh Island	Nitinat
Arrival Time	03/05:00Z	03/07:00Z	03/09:24Z
Gravity Current Velocity(knots)	17.0	18.0	15.0

It is difficult to track the motion of this stratus cloud at night using the infrared GOES satellite imagery. From the visual image for 18:46Z on the 3rd (Fig.3) however, one can see that the stratus had progressed up the Vancouver Island coast to just beyond 50 degrees N. Assuming that the leading edge of the stratus was at Destruction Island at 05Z on the 3rd, then this would correspond to a motion of 15 knots. This agrees quite well with the gravity current estimate.

When one compares the 18:46Z satellite images for the 2nd and 3rd (Figs. 1 and 3), they might conclude that the cloud pattern in Fig. 3 simply resulted from an onshore drift of the stratus which was initially off Northern Vancouver Island. The Washington Coast observations however, indicated a northward progression of stratus on the evening of the 2nd which must have originated off the Oregon Coast. Animation of the visual satellite imagery on the 3rd also clearly shows a narrow tongue of stratus surging northwestward along the coast of Vancouver Island. On the morning of the 3rd, winds along the Vancouver Island were stronger than the 18Z surface pressure gradient would suggest (Fig. 4), particularly in such a stable flow. Estevan Point half way up Vancouver Island reported southeasterlies gusting to 22 knots. Meanwhile shortly after the stratus arrived at Solander Island, just off the Brooks Peninsula, winds peaked with southeast gales of 38 knots. Such windspeeds are typical during an alongshore stratus surges and support the existence of a gravity current or Kelvin wave.

In order to initiate either a gravity current or a Kelvin wave, some onshore forcing is required and in this case the mechanism appears to be very weak. The 18Z surface analysis on the 3rd (Fig. 4) identified a minor 1015 millibar low off northern Vancouver Island which may have originated as the 1013 millibar low on the 18Z analysis on the 2nd. Assuming this was indeed the case, then a light southwest flow would exist near the southeast quadrant of the low and direct the stratus initially against the Olympic Mountains and later against the slopes of Vancouver Island. The northwestward drift of this low would help sustain a gravity current. Since this low lingered off the mouth of the Columbia most of Sept. 2nd, some synoptic scale feature must have forced it to move northward after 00Z on the 3rd. A 20 to 30 knot southerly 500 millibar flow was present along the west coast from the 2nd to the 4th of Sept (Fig. 6). Temperatures at the 500 millibar level and a narrow band of high cloud on the satellite imagery both supported the existence of a weak cold upper trough which moved northward into Oregon at 00Z on the 3rd. This feature produced weak pressure rises on the Oregon coast which may have started the low on a northward journey and launched the stratus surge.

CONCLUSIONS

The alongshore stratus surge of Sept. 3 1988 exhibited many of the characteristics of a topographically trapped gravity current, particulary along the Washington Coast. It was not a classic example of this mesoscale process. The weak offshore low and the area of stratus off of northern Vancouver Island added some complications. This event appeared to be triggered by very weak synoptic scale forcing which, however caused, a major change in the weather along the west coast of Vancouver Island, and it was selected to illustrate that very point. Although difficult, the forecasting of an alongshore stratus surge along the B. C. coast is not impossible. They are usually proceeded by a warm offshore flow and require an extensive area of stratus, usually positioned off the Oregon coast which is easily detected by visual imagery. Once the surge reaches the Washington coast, the gravity current velocity formula may be used to estimate arrival times, especially during night time events. Similar surges have been observed in Australia and they likely occur in many other areas such as the Chilean coast and along the north coasts of Alaska and the Yukon.

Acknowlegements

I would like to thank Gerard Neault and Lawrence Chu of the Pacific Weather Centre as well as Dr. D.G. Steyn of U.B.C. for the their valuable discussions concerning this topic. Thanks must also go to Jay Anderson for obtaining satellite animation loops.

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Fig.1 GOES Visual Imagery 18:46Z 02Sep88

Fig.2 Sfc Anal 18Z 02Sep88

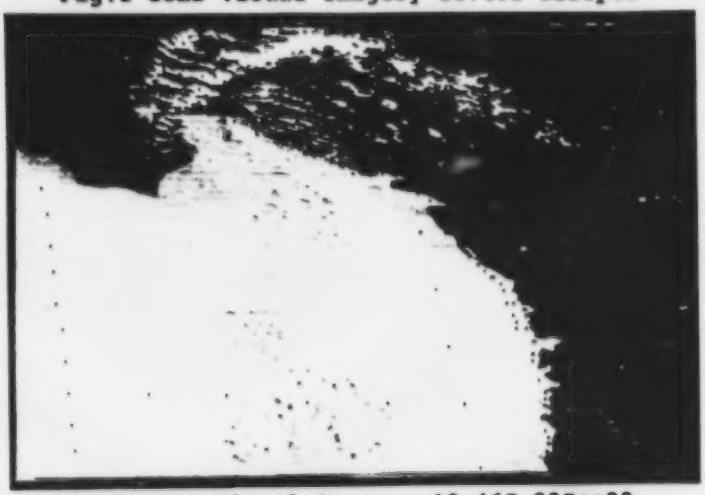

Fig.3 GOES Visual Imagery 18:46Z 03Sep88

Fig.4 Sfc Anal 18Z 03Sep88

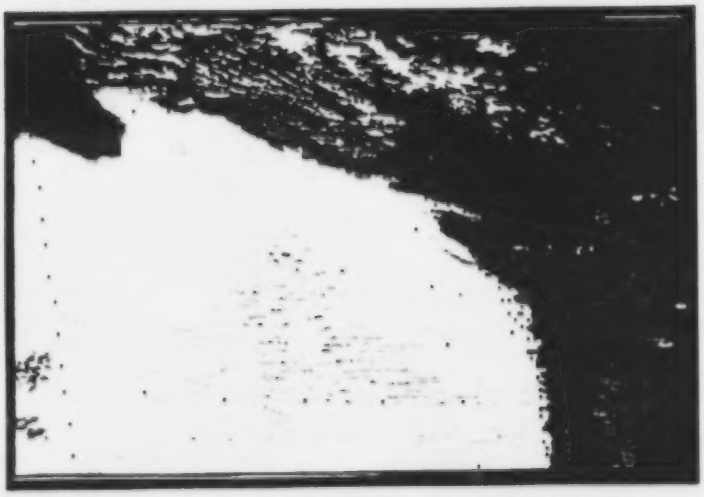

Fig.5 GOES Visual Imagery 21:46Z 03Sep88

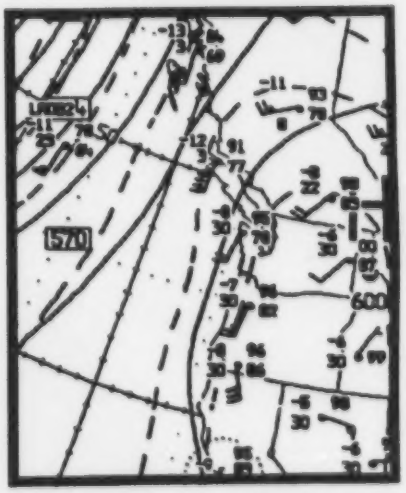

Fig.6 500 MB Anal 00Z 04Sep88

SNOW FORECASTING USING PHYSICAL PARAMETERS

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RÉSUMÉ

Une technique de prévision des accumulations de neige développée au Centre météorologique du Québec (CMQ) est présentée ici. Cette technique résulte d'une étude systématique d'une quinzaine de systèmes synoptiques qui ont affecté la province de Québec. A l'aide de la théorie quasi géostrophique, nous avons évalué quantitativement les paramètres physiques directement responsables des précipitations et nous les avons corrélés aux accumulations de neige observées à différentes stations. Les paramètres utilisés furent les suivants: l'advection de tourbillon à 500 mb par le vent thermique moyen dans la couche 1000-500 mb, la quantité d'eau précipitable, le tourbillon géostrophique à 1000 mb et sa variation locale, la tendance des épaisseurs 1000-500 mb.

ABSTRACT

A technique has been developed to help forecasting snow amounts. This technique is the result of a systematic study of 15 synoptic systems that affected the province of Quebec. For these systems, we related together the snow amounts observed at different stations to the quantitative assessment of the physical parameters directly responsible for precipitation, using the quasi-geostrophic theory. The parameters used were the 500 mb vorticity advection by the thermal wind (1000-500 mb thicknesses), the precipitable water, the 1000 mb vorticity and its tendency, the 1000-500 mb thickness tendency.

1. INTRODUCTION

The forecast of snow accumulations requires first a thorough evaluation of the synoptic features responsible for the formation of precipitation. These elements include the vertical velocity and the available moisture in the atmosphere. We must also evaluate related parameters that are more difficult to quantify, such as stability and local effects. Finally the duration of the precipitation event as well as possible changes in precipitation type must be taken into account.

As the purpose of this paper is to deal with snow episodes and related accumulations, we will from now onwards assume that the precipitation type is known or determined by other techniques.

The usual tools available operationally to forecast snow accumulations are:

- the QPF from the numerical models, which are nowadays quite good but nevertheless not always reliable.
- statistical and empirical techniques. These often give relevant indications but do not forecast precise quantities.

We then need to have a technique to complete the information obtained by the above mentioned tools and to assess the NWP QPF's for each particular case.

2. THE TECHNIQUE

To achieve this goal, a systematic study of synoptic systems that affected the province of Quebec was undertaken. We tried to relate the snow episodes and amounts observed with these systems to the values of the physical parameters directly responsible for precipitation, using the quasi-geostrophic theory.

To assess the vertical velocity in the mid-troposphere, we used Trenberth's formulation of the omega equation which states that vertical velocity can be accounted for by evaluating the advection of vorticity by the thermal wind.*

The parameters used to evaluate the low level vertical velocity are the 1000 mb geostrophic vorticity and its tendency.

A qualitative assessment of the temperature advections and air mass stability is performed by taking into account the 1000-500 mb thickness tendency.

Finally, the available moisture is directly accounted for by the precipitable water content in the surface-400 mb atmospheric layer.

2.1 TECHNIQUE DEVELOPMENT

A. Database

Fifteen meteorological systems that affected the province of Quebec were used. From these 15 weather systems, we could extract about 175 snow episodes of about 12 hours at different observation stations.

B. Types of systems

Because of the type of synoptic situations studied, the results of the technique apply with more reliability in cases where:

- the weather systems are in translation with a mean speed of the order of 20-25 knots.
- the systems are supported aloft by a well defined vorticity centre which maintains its identity in time.

C. Parameter variations

With this type of systems, we can usually identify a maximum of Vorticity Advection by the Thermal Wind (VATW). This maximum may vary in intensity but maintains its identity in time so that we can track it. Then we can relate together the snow episodes and the parameters used in two types of situations:

- when VATW is increasing in time, i.e. the maximum of VATW is approaching a region;
- when VATW is decreasing, i.e. the maximum of VATW is moving away from a region.

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* Trenberth, Kevin,E.,1977: On the interpretation of the Diagnostic Quasi-geostrophic Omega equation, Monthly Weather Review, Jan. 1978, Vol.106, No.1, p.131-137.

D. Data extraction

For the sake of brevity, we will examine only the more important snow episodes corresponding to increasing VATW during 12-hour periods.

For these periods, the snow amounts were related to the following features:

- the MAXIMUM values of VATW, Qg (1000 mb geost. vorticity) and PCPTW (precipitable water) reached during the periods;
- the variation of Qg during the period (usually an increase in this case);
- the sign of the 1000-500 mb thickness tendency.

With surface lows moving at about 25 knots, the above correlations could be made for snow episodes of about 12 hours duration. This is not really a limitation, since we can then adjust the accumulations given by the resulting tables to the translation speed of the systems.

We will now examine how the different parameters are evaluated operationally and how they relate to snow amounts.

2.2 EVALUATION OF THE PHYSICAL PARAMETERS

A. Vertical velocity in the mid-troposphere (fig. 1)

To visualize and evaluate the VATW (Vorticity Advection by the Thermal Wind), we use, as proposed by Trenberth, the superimposition of the 1000-500 mb thickness lines to the absolute vorticity field at 500 mb.

To quantify the advection values, we defined a "surface advection unit" to which we arbitrarily assigned the relative value of 100 units. (This surface advection unit is shown on fig. 1). This advection surface of 100 units corresponds approximately to a real advection value of 2.75 x 10**-9 /sec/sec.

To give an idea of the representative values of advection, we can note that, as indicated in the table at the bottom of the fig. 1, when sufficient moisture is available, maximum values of VATW of the order of 100 moving over a region correspond frequently to accumulations of 10-15 cm of snow whereas when the maximum reaches or exceeds 200, we usually observe snow amounts exceeding 15 cm.

(Note that Vt in the table is a shorthand for VATW.)

It should be remembered that these correlations are for 12-hour periods and for increasing VATW.

B. Precipitable Water (PCPTW) (fig. 2)

To estimate the available moisture in the atmosphere, we use fields of precipitable water in the surface-400 mb atmospheric layer.

Fig. 2 shows a precipitable water analysis from the Canadian RFE (Regional Finite Elements) model, showing contours of precipitable water at every 5 mm. These fields are available on an operational basis at analysis and prognosis times, as are also the other fields in (A) above and (C) below.

The critical lines are the 10 and 15 mm contours. In summary, when vertical velocity is sufficient, snow amounts of 15 cm or more generally require a precipitable water value of at least 10 mm. On the other hand, when precipitable water is less than 7 mm, we rarely observe accumulations reaching 10 cm. Finally, when precipitable water exceeds 15 mm, the moisture potential for snow amounts is maximised.

C. Low level vertical velocity (fig. 3)

The low level vertical velocity is accounted for in the technique by the 1000 mb geostrophic vorticity (Qg) and its variation [D(Qg)].

The fields used are analysis and prognosis of 1000 mb geostrophic vorticity in units of 10**-5 /sec contoured every 2 units.

As expected, maxima of geostrophic vorticity are associated with surface lows. The instantaneous values of Qg are proportional to the vertical velocity in the boundary layer.*

What is mainly considered is the local time variation of the 1000 mb vorticity during the snow episodes, as this represents convergence and vertical velocity at low levels. (Zwack et al.,1984)

Snow amounts are generally somewhat less sensitive to this parameter than they are to VATW and PCPTW. But it is nevertheless important as it allows to refine anticipated snow amounts.

To give an idea of the representative values, we can note that, if sufficient moisture and mid-tropospheric vertical velocity are available, a variation of Qg exceeding 5 units during the period considered indicates accumulations approaching 10 cm, whereas an increase of Qg of more then 10 units makes it favourable to amounts of 15 cm or more.

2.3 RESULTS (fig. 4)

Figure 4 shows the correlations obtained between the MAXIMUM values of VATW, MAXIMUM values of PCPTW, and SNOW AMOUNTS for 12-hour periods of snow when VATW is increasing.

The right-hand side of the figure considers cases for which thicknesses (DZ) are increasing, whereas the left-hand side relates to cases for which thicknesses (DZ) are decreasing.

In first approximation and for the sake of clarity, we will not consider at this point the 1000 mb geostrophic vorticity predictor.
Snow amounts indicated in fig. 4 are in centimeters (Cm).

For example, in the case of increasing DZ where predictors highest values are greater than 200 for VATW and greater than 15 mm for PCPTW, we generally observe 12-hour accumulations of 25 cm or more.

On the other hand we note that, as expected, for equivalent conditions of PCPTW and VATW, snow accumulations will be larger when DZ is increasing during the period than when DZ is decreasing; occluding systems are a good example of the latter situation.

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* Holton, J.,1972: An introduction to dynamic meteorology, Academic Press, New-York and London, 319 pp.

* Zwack, P. and G. Babin, 1984: Using Quasi-geostrophic theory to understand lower troposphere synoptic scale vertical motion, 10th Conf. on Wea. For. and Anal., Amer. Meteor. Soc., Clearwater Beach, Fla., June 1984, pp. 256-264.

The influence of the 1000 mb geostrophic vorticity (Qg) and its variation is shown in the table at the bottom of fig. 4. For important increases of Qg, especially for increases of 10 units or more, snow accumulations will be significantly larger than the means indicated on the figure.

3. CASE STUDY - NOVEMBER 25-26, 1987

This case study will be presented at the workshop to illustrate the application of the technique.

It is already available in a Technical Note that was published in April 1989.*

4. LIMITATIONS

The limitations to the technique are of two types:

4.1 Representativity of the parameters

Some phenomena are not well represented by the parameters used:

- Local effects such as orography and on-shore flow must be evaluated from experience or other techniques.

- Warm air advection is not always well represented by VATW in the way it is currently produced. Sometimes, when warm air advection at low levels is far ahead of the system and of the 500 mb vorticity centre, then there are no vorticity lines in the area of temperature advection so that there is no vorticity advection shown since the vertical velocity is all accounted for below 500 mb.

- VATW is a representative and important forcing term for the vertical velocity (VV) but it is not the only term involved. Hence, in certain situations where the other terms (i.e. diabatic heating, latent heat release, etc.) are larger, VATW will give an erroneous visualization of the VV field aloft.

- Also to be considered is the consequence of having models with higher horizontal resolution. This has a very marked effect on the resulting vorticity fields, as shown by studies at CMC (Centre météorologique canadien) and RPN (Recherche en prévisions numériques): the vorticity fields are analysed and forecast with increased values of MAX and MIN centres, increased gradients and increased detail. This has a negative impact on our technique which works best with synoptic or near synoptic scale models.

4.2 Accuracy of the forecast parameters

The accuracy of the forecast parameters also limits sometimes the usefulness of the technique.

The Qg, DZ and PCPTW parameters are generally reliable forecast parameters. But on the other hand, the reliability of the 500 mb forecast vorticity depends on the synoptic situation. In some particular cases, like channeled jets and shear lobes maximum vorticity in a strong circulation, vorticity centres and gradients are often poorly predicted by the numerical models.

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* Bachand D., Turcotte V. and Morisette J.: "Snow Forecasting Using Physical Parameters", Technical Note, Quebec Region, April 1989, Number 89N-001.

5. LATEST DEVELOPMENTS

Further case studies have allowed us to refine the interpretation of the parameters and the forecast of snow amounts in different synoptic situations, for example:

- in the comma head of a low pressure system;
- in cases of low level instability (below 850 or 900 mb), for instance in the warm sector of a low when the vertical temperature profile remains below zero degre Celsius, except perhaps close to the surface.

Since November 1988, objectively computed VATW at both analysis and prognosis times is available in contoured charts, thus allowing direct extraction of VATW values.

The use of VATW at 850 mb, also computed objectively since last winter, completes the information given by VATW as evaluated with the 500 mb vorticity and the 1000-500 mb thicknesses. It is particularly useful in cases of warm air advection not superimposed upon the 500 mb vorticity, as pointed out above in the section dealing with technique limitations.

The cases studied also showed the importance of the phase correlation between VATW at 850 mb and 500 mb, the resulting VV aloft and snow accumulations being much larger in cases where VATW maxima at both levels are superimposed.

6. CONCLUSION

6.1 Advantages

The advantages of the technique include the following:
- it allows the evaluation of individual physical parameters for each weather system;
- it allows to assess the NWP model's QPF;
- it gives directly snow amount forecasts;
- being a "Perfect Prog" type approach, it is applicable to any NWP model with a similar horizontal resolution to the one used in the development of the technique.

6.2 Future development

We intend to increase the statistical sample by studying new cases.

The correlations tables would then be upgraded by including directly the 850 mb VATW parameter which is now considered seperately.

We also intend to make an objective comparison of the VATW parameters with the VV fields from the numerical models at different levels (sigma=.91, 850 mb, 700 mb), on an analysis and prognosis basis.

In longer term perspective, and in view of the problems with vorticity at higher resolution, as mentioned above, correlations will have to be made with VV fields of the models only, unless we can have available a synoptic scale vorticity field accompanying the model. It is to be hoped that this will be considered seriously by the researchers since the synoptic or near synoptic scale vorticity field is a most important tool in operational meteorology allowing the extraction of some useful information from the model.

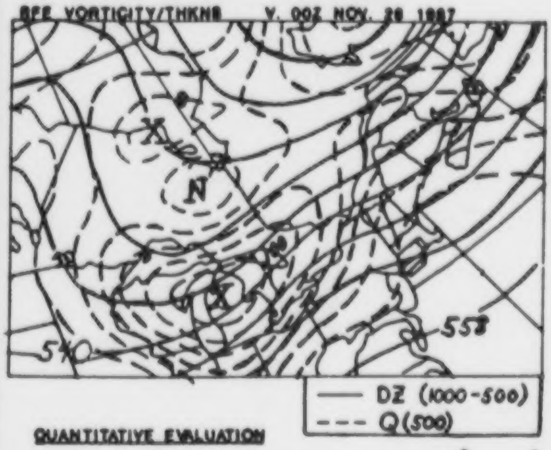
Finally, we can say, as a general evaluation of the consequences of the use of this technique at CMQ, that it has definitely contributed positively to the accuracy of snow amount forecast in the past few winter seasons.

Fig.1

VERTICAL VELOCITY IN MID-TROPOSPHERE

TRENBERTH'S FORMULATION FOR OMEGA

RFE VORTICITY/THKNS V. 00Z NOV. 26 1987



QUANTITATIVE EVALUATION

UNIT ADV. SURFACE = 100 ⟷ 2.75×10^{-9} SEC^{-2}

REPRESENTATIVE VALUES

V_T	SNOW AMOUNTS
100	10-15 CM
200	> 15 CM

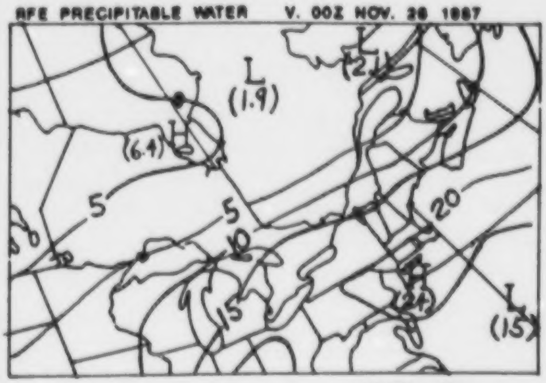
⟺ IF SUFFICIENT MOISTURE AVAILABLE

Fig.2

AVAILABLE MOISTURE

TOTAL PRECIPITABLE WATER IN THE ATMOSPHERE

RFE PRECIPITABLE WATER V. 00Z NOV. 26 1987



UNITS : MM

REPRESENTATIVE VALUES

PCPTW	SNOW ACC.
7 MM	10 CM
10 MM	15 CM
15 MM	20-25 CM

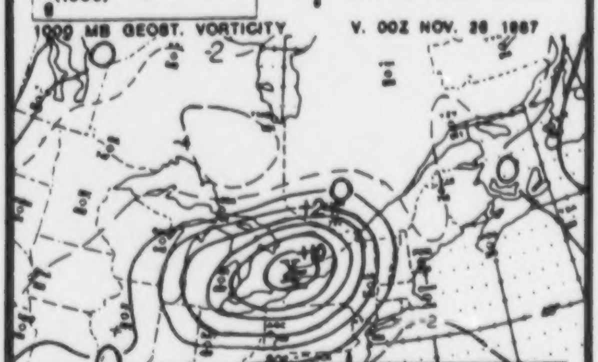
⟺ IF SUFFICIENT VERTICAL VELOCITY

Fig.3

LOW LEVEL VERTICAL VELOCITY

$Q_g(1000) = g/f\ (\nabla^2 Z)$ Q_g = f(V.V. IN SNOWY LAYER)

1000 MB GEOST. VORTICITY V. 00Z NOV. 26 1987



UNITS : (10**-5)/SEC NEGATIVE VORT. POSITIVE VORT.

LOCAL VARIATION OF VORTICITY – WIND DIVERG.
|
LO-LVL V.V.

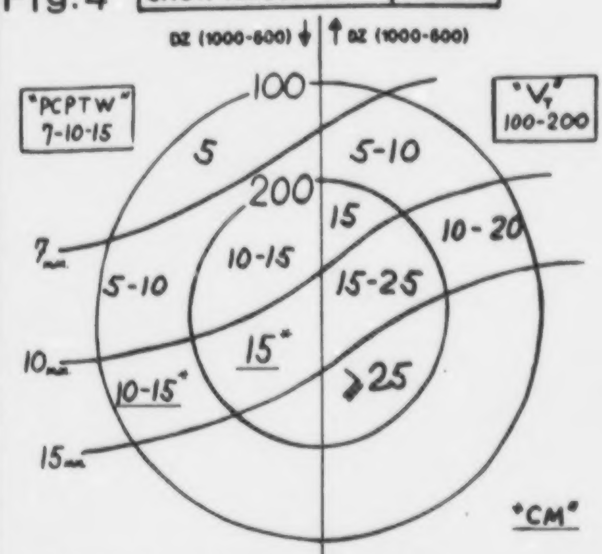
REPRESENTATIVE VALUES

δQ_g	SNOW AMOUNTS
> 5	10 CM
> 10	15 CM

⟺ IF SUFFICIENT MOISTURE AVAILABLE

Fig.4

SNOW AMOUNTS - "V_T" RISING



* EXTRAPOLATED VALUES ... NOT YET VERIFIED

INFLUENCE OF THE VARIATION OF THE 1000 MB VORTICITY

$\delta(Q_g)$	DZ	V_T	PCPTW	ACCUMULATION
>5	↑	100-200	7-10	10-15 cm.
>10	↑	≥200	7-10	15-25
>10	↓	≥200	7-10	15-20

MESOSCALE VERTICAL VELOCITY AND SURFACE CONVERGENCE FIELDS IN THE LEE OF THE ALBERTA ROCKIES: A CASE STUDY

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ABSTRACT

Surface and upper air data from the 1985 Alberta Limestone Mountain Experiment (LIMEX-85) are used to test the validity of some dynamical aspects of a multi-scale conceptual model of thunderstorm genesis as it applies to the Alberta situation. Vertical velocity fields are estimated using the adiabatic technique, and are compared with surface divergence fields. These fields are then discussed in relation to satellite and radar data that detected the evolution of the thunderstorms. In particular, the results confirm the occurrence of low-level ascent and surface convergence up to six hours prior to storm formation.

Les données en surface et en altitude du projet Alberta "Limestone Mountain Experiment" de 1985 (LIMEX-85) ont été utilisées pour vérifier la validité de certains aspects dynamique du modèle conceptuel à plusieurs échelles concernant le développement d'un orage typique de l'Alberta. Les champs de mouvement vertical sont calculés à partir de la méthode adiabatique, et ensuite comparé avec les champs de divergence en surface. On relie ensuite ces champs aux données satellites et radars qui nous donné de l'information concernant l'évolution des orages. Les resultats comfirment que pour une période allant jusqu'a 6 heures avant la formation d'un orage, la présence de convergence en surface de même que de l'ascendance dans les bas niveaux, sont observées.

INTRODUCTION

Severe summer convective storms are a common occurrence over the great plains east of the Rocky Mountains barrier from Alberta to Texas, with a very high frequency over the foothill regions in the immediate lee of this barrier. In Alberta, such storms form most frequently over the smaller foothill ridges during the approach of a synoptic scale weather system (Strong, 1986). Strong described a multi-scale conceptual model of Alberta thunderstorm genesis which describes why, when, and how synoptic scale processes create a favourable mesoscale environment for convective storms. Some aspects of this conceptual model were tested using data from the SESAME AVE-IV and

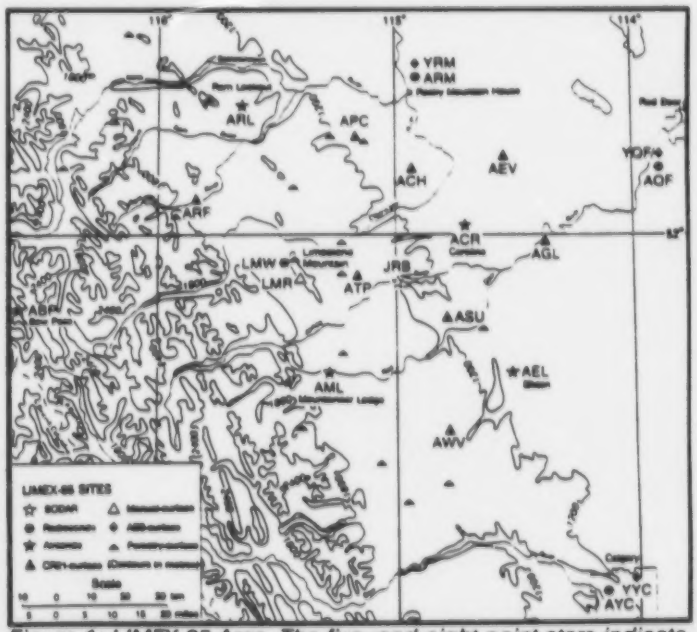

Figure 1: LIMEX-85 Area. The five- and eight-point stars indicate the nine upper air stations involved in LIMEX-85.

AVE-V mesoscale experiments* of May, 1979 over Oklahoma (Strong, 1986).

During the early 1980's, a series of mesoscale field experiments, collectively called the Limestone Mountain Experiments (LIMEX), were also carried out over the foothill regions of southwestern Alberta, specifically to test various portions of the conceptual model (Strong, 1986). LIMEX field experiments commenced with LIMEX-80 (15-17 July, 1980) and culminated with LIMEX-85 (08-23 July, 1985). During LIMEX-85, nine radiosonde systems were deployed at 50-60 km spacings over the foothills, providing soundings at two-hour intervals (see Figure 1). Surface data were collected from an average site spacing of 20 km. Details of the LIMEX data sets are described by Strong (1989).

This paper discusses preliminary tests of the conceptual model from the perspective of the mesoscale dynamics of 11 July, 1985 during LIMEX-85. We use an adiabatic technique to compute vertical motion fields from the upper air data, and compare these fields with surface convergence fields computed from the independent surface data set. Significant features of these fields are related to convective entities as recorded by radar, satellite, and surface observations.

DATA ANALYSIS

Methodology of Estimating Environmental Vertical Velocity

It is beyond the scope of this paper to describe the adiabatic method of estimating vertical velocity. The modified adiabatic technique presented by Strong (1986) was adopted for use on the LIMEX data in this study. For further details see Honch (1989).

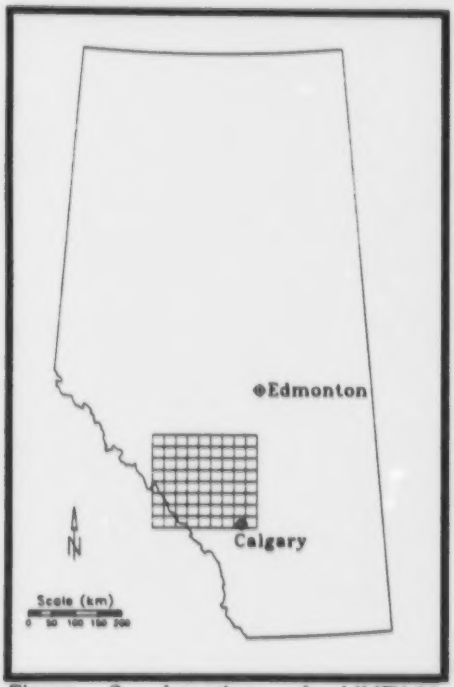

Figure 2: Location of LIMEX-85 mesoscale analysis grid.

Mesoscale Objective Map Analysis

The mesoscale objective map analysis technique used in this study is based on a scheme developed by Barnes (1964, 1973). The location of the analysis grid is displayed in Figure 2. The LIMEX-85 mesoscale analysis grid, with upper air station locations, is shown in Figure 3.

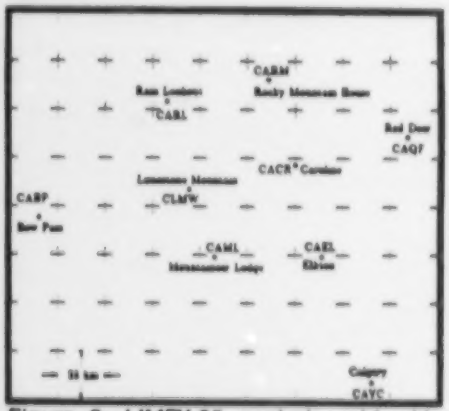

Figure 3: LIMEX-85 analysis grid with the nine upper air station locations.

SYNOPTIC SITUATION

A brief summary of the synoptic situation on July 11, 1985 follows. A more detailed description, complete with figures, is found in Honch (1989).

The key features in the synoptic analyses are:

1) a west-southwesterly flow in the mid- to upper-troposphere with an approaching synoptic shortwave;

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* SESAME - Severe Environmental Storms And Mesoscale Experiments
AVE - Area Variability Experiment

2) 250 mb jet streak with speeds in excess of 100 knots extending from Port Hardy, B.C. to Red Deer;
3) weak area of PVA at 500 mb approaching from central B.C.;
4) weak cyclonic flow over central Alberta in the lower troposphere, with a decaying low pressure centre southeast of the LIMEX network.

These features are typical of the severe storm patterns described by Strong (1986).

S-BAND RADAR PPI SUMMARIES

S-band radar PPI's provide a mesoscale summary of the convective events on July 11. The complete series of PPI summaries (see Honch, 1989) indicate that showers initially developed over northern sections of the LIMEX-85 network after 2300 UTC. The reflectivities were initially less than 30dBZ; however, shortly after 0100 UTC, July 12, the reflectivities increased to greater than 50dBZ. This evolution suggests that towering cumulus clouds giving the showers at 2300 UTC matured to a thunderstorm by 0100 UTC. This thunderstorm then moved east-northeastward out of the network at a speed of 40 km hr^{-1} (see Figure 4).

Figure 4: S-band radar PPI summary for 0100 UTC July 12, 1985. Distance rings are spaced at intervals of 20 km. Reflectivity is contoured in intervals of 10dBZ starting at 20dBZ.

MESOSCALE VERTICAL MOTION FIELDS

One of the objectives of this study was to determine whether pronounced positive vertical motion is prevalent in the atmosphere up to 6 hours prior to a thunderstorm event. The spatial objective analysis of the late morning (1700 UTC) vertical motion field (Figure 5) is characterized by general ascent over regions east of the foothills. This pattern is interrupted by relatively strong subsidence near 750 mb (primarily orographically induced), just above the capping lid (Figure 6).

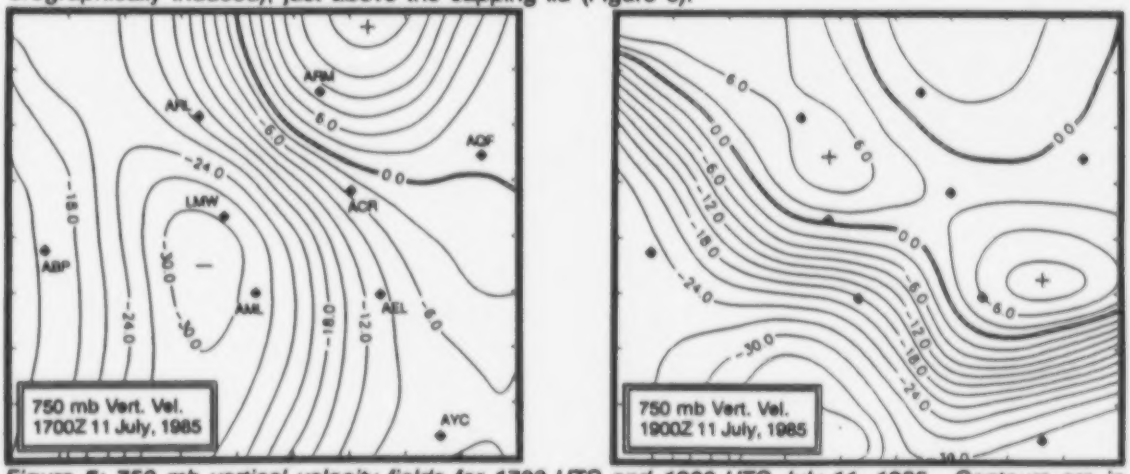

Figure 5: 750 mb vertical velocity fields for 1700 UTC and 1900 UTC July 11, 1985. Contours are in intervals of 6 cm s^{-1}. Centres of positive vertical motion (ascent) are indicated by "+". Centres of subsidence are indicated by "-".

By early afternoon (1900 UTC), this orographic subsidence is gradually giving way to small cells of ascent over northern sections of the LIMEX-85 network, with maximum values around 10 cm s^{-1} at 750 mb (see Figure 5). These well defined cells of ascent appeared approximately 6 hours prior to the development of convective precipitation; recall, that the first significant radar echoes appeared to develop over northern portions of the LIMEX network near 0100 UTC, July 12 (Figure 4). Inspection of the soundings in Figure 6 reveals that the capping lid is weakening over northern sites, no doubt due to cooling caused by ascent.

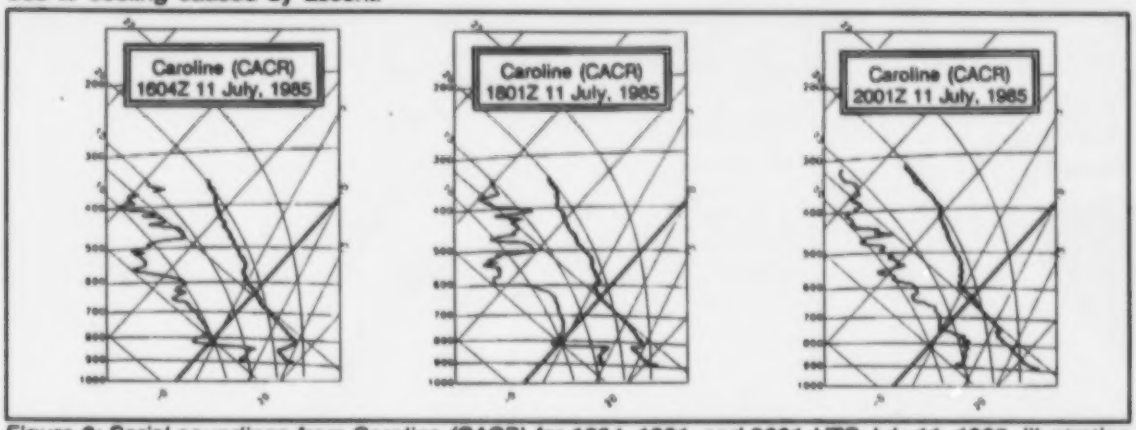

Figure 6: Serial soundings from Caroline (CACR) for 1604, 1801, and 2001 UTC July 11, 1985, illustrating the evolution of the capping lid.

MESOSCALE SURFACE DIVERGENCE FIELDS

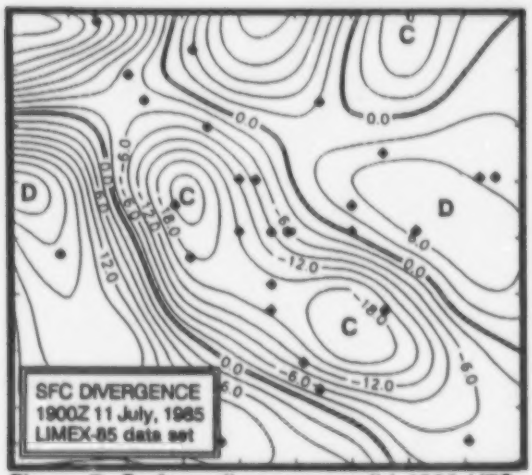

Figure 7: Surface divergence valid 1900 UTC. Contours are in intervals of $3x10^{-5}s^{-1}$. Centres of convergence are indicated by the letter "C" (negative divergence). Centres of divergence are indicated by the letter "D".

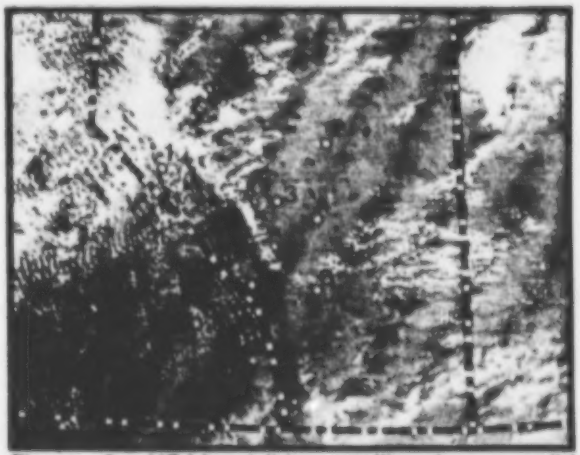

Figure 8: NOAA visible satellite image valid 2134 UTC July 11, 1985. The numbered sites denote AES surface synoptic sites at: (1) Jasper, (2) Edmonton, (3) Rocky Mountain House, (4) Red Deer, (5) Banff, and (6) Calgary.

The mesoscale surface divergence fields for 1700-2300 UTC (see Honch, 1989) are characterized by a strong "line" of convergence that extends from the northwest corner of the grid southeastward (see Figure 7). The position of this "line" of convergence corresponds well with the

2134 UTC visible satellite image (Figure 8). The satellite image clearly indicates a band of cumuliform cloud developing over the region of strong surface convergence.

We note also that the line of convergence (and band of cumuliform cloud) developed over the foothills in the immediate lee of the Rockies. This concurs with Barker and Banta (1984, 1985), who hypothesized that in mountainous terrain, zones of convergence occur on the leeward side of the mountain ranges where the upslope airflow encounters well-mixed downslope flow at the surface. Barker and Banta found that zones of convergence precede the development of convective storms, and concluded that these zones were the regions of thunderstorm initiation. Strong (1986) hypothesized that these mesoscale dynamic features result from a combination of a downscale transfer of eddy kinetic energy, particularly during cyclolysis, and orographic forcing due to an easterly component of boundary layer flow north of a synoptic low pressure centre. These LIMEX-85 analyses support both hypotheses to a degree.

THE UTILITY OF EXISTING SUB-SYNOPTIC DATA SOURCES

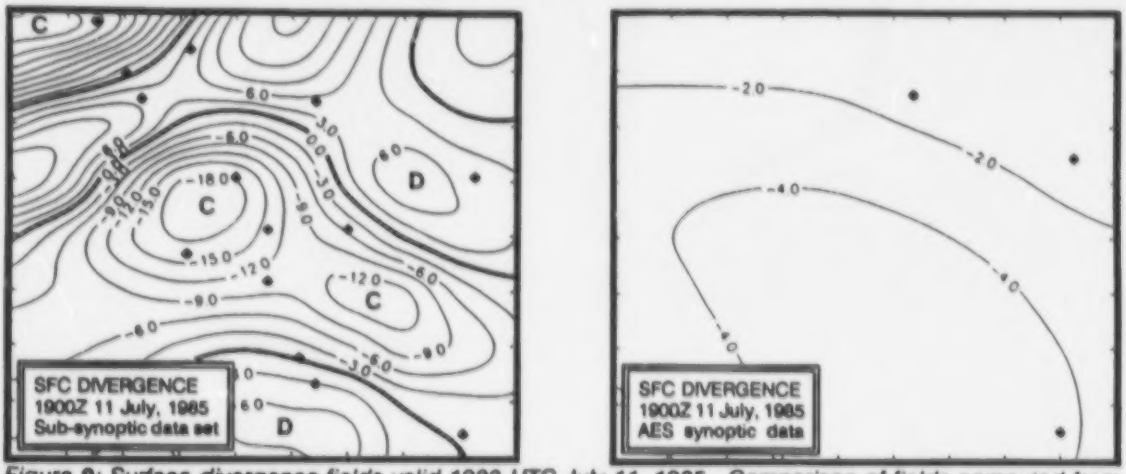

Figure 9: Surface divergence fields valid 1900 UTC July 11, 1985. Comparison of fields computed from (A) an existing sub-synoptic data source (combination of both Alberta Forestry and AES synoptic sites) and (B) the AES synoptic sites alone.

A secondary objective of this study was to determine the usefulness of non-regular surface data sources. Figure 9 shows the computed mesoscale surface divergence fields for 1900 UTC, first, by using both Alberta Forestry and operational AES data (combining to form a sub-synoptic data source), and second, using only the operational AES synoptic data. Initial inspection of the sub-synoptic analysis indicates that significant information can be ascertained from this data source. Recall that the mesoscale surface divergence analysis (Figure 7) revealed strong convergence in the Limestone Mountain area, with a line of convergence extending southeastward. This line of convergence is also evident in the sub-synoptic analysis, though not as intense. In general, one finds the overall patterns on the sub-synoptic scale analysis quite similar to those of the mesoscale analysis. In sharp contrast, the synoptic scale analysis only vaguely hints at the existence of weak convergence over central portions of the network and is unable to resolve the strong line of convergence in the lee of the Rockies. These results suggest that information not readily apparent on a synoptic scale analysis could be easily obtained by employing the Alberta Forestry data.

CONCLUSIONS

The initial results of LIMEX-85 indicate the presence of strong positive vertical motion in the low- to mid-troposphere 5-6 hours prior to the thunderstorm event. The timing of and strength of this ascent and associated surface convergence suggest sources in addition to the dynamics induced by convection from differential surface heating, or by orographic forcing. The presence of strong surface convergence along the lee side of the Rocky Mountains supports the premise that links surface convergence with thunderstorm initiation. These results support several aspects of the conceptual model proposed by Strong (1986), and concur with results that he obtained using the 1979 Oklahoma-Texas SESAME data.

For operational forecasting of convective weather, these initial results also demonstrate that existing surface data, when combined with the Alberta Forestry weather data, could be used to obtain useful operational diagnoses of surface divergence fields in the lee of the Alberta Rockies.

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DEW POINT DISCONTINUITY INITIATES SEVERE THUNDERSTORMS IN UTAH

By

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A B S T R A C T

The retrieving and analysis of hourly surface observations is critical for the operational forecaster to capture the development and movement of meso-scale features, especially those surface features which are not resolved by computer guidance. Dev point discontinuities are features that are rarely discernible on guidance output, but may be an important weather producer. This study reveals hov one such strong dev point gradiant acted as the trig-ger mechanism for severe thunderstorms in Utah. The combination of surface convergence, advection of the 700 mb baroclinic zone, and strong diffluence associated with the left front quadrant of the 300 mb jet produced an envi-ronment of strong vertical motions.

Aller chercher et analyser les observations horaires s'avère critique pour le prévisioniste afin de saisir le développement et le déplacement des structures à mésoéchelle , surtout celles mal résolues par les modèles numériques. Les discontinuités de point de rosée sont un exemple et elles peuvent engendrer du temps significatif. Cette étude montre comment un fort gradient de point de rosée a déclenché des orages violents en Utah. La combinaison de convergence de surface, d'advection de la zone barocline à 700 mb et d' une forte diffluence associée à la sortie gauche du jet à 300 mb ont produit une région de mouvements ascendants forts.

I N T R O D U C T I O N

On May 11, 1989, a cold 500 mb cut-off lov moved into the Great Basin from southern California. An active day of thundershovers was forecast across the region, with ample lov-level moisture in place and cooling aloft as the 500 mb temperatures decreased below -20°C. Although some isolated thundershovers occurred between Dugvay Proving Ground (DPG) and the Salt Lake City (SLC) valley during the early forenoon, most of the midday cloud development was suppressed. Between 1830Z and 1930Z, an area of organized convection develo-ped in the vicinity of Delta, UT (U24). This area expanded along an appar-ent axis oriented from southvest to northeast and moved north, producing se-vere weather from near DPG to north of SLC. Severe weather reports included several funnel clouds, a tornado, and numerous reports of 2 cm or greater di-ameter hail.

What vas the focusing mechanism that produced these thunderstorms? It is apparent that a trigger mechanism existed south of DPG but north of U24, for this was the area in which the thunderstorms developed in a line. Although higher terrain exists here, it is believed that the dev point discontinuity in the boundary layer provided the necessary surface convergence. Positive vorticity advection and diffluence at 300 mb provided additional upvard ver-

tical motion.

Storm Synopsis

A moderately cold cut-off low entered the southern Great Basin on May 11, with temperatures of -20°C or colder across Nevada and most of California. Edwards AFB reported -25°C. The cut-off low had progressed due east since 00Z, but was forecast by the Nested Grid Model (NGM) to curve slightly north of east during the next 12 hours, to a position near St. George, UT. This movement, in combination with a vorticity lobe moving northward across Utah during maximum heating of the afternoon, provided for increased instability. The 500 mb dew point depressions, however, were greater than 15 degrees across southern Nevada, Arizona, and southern California. This was misleading, though, because the 12Z sounding from Ely, NV (Fig. 4) indicates moisture was in adequate supply from 520 mb down to the surface with 1.12 cm of precipitable water. At SLC, the precipitable water was 1.56 cm from 500 mb to the surface.

At 300 mb at 12Z (Fig. 1), a 70 kt southerly jet was moving through Arizona and into Utah, with a 90 kt jet core rounding the base of the trough. Noticeable is the wind shear and directional diffluence over the region between SLC and the 300 mb low. This area of upward vertical motion associated with the left front quadrant of the jet was forecast to remain over the region for the following 6 to 12 hours, coinciding with the maximum heating of the day.

The lower levels were also primed to produce thunderstorm activity. At 700 mb, a large pool of relatively warm dew points (warmer than -5°C) existed over eastern Nevada and at least western Utah. These, in combination with the advection of a moderately strong baroclinic band across central and northern Utah between 18Z and 00Z, were additional ingredients supplying instability. At the surface, dew points were between 5°C and 10°C across northern Utah. The exact location of the weak cold front was hard to determine due to sparsity of observation stations. But from the few that did report, it was determined that the cold front stalled along an east-west axis from near Wendover, UT (ENV) to the vicinity of SLC. The 12Z SLC sounding (Fig. 3) indicates backing winds from the surface to 2500 m supporting cold advection and, therefore, a frontal passage. However, the temperature profile, with a surface inversion, supports a prefrontal sounding. These conflicting observations may be explained by the convective activity that was present the previous night, causing a diversity of wind flow patterns that are indicative of outflow boundaries. In either case, the location of the front was eventually analyzed south of Lakeside, UT (U16), but north of DPG through at least 19Z. Then, when the lightning activity increased rapidly south of DPG (Fig. 5), some other surface feature must obviously have provided the low-level convergence, fueling the thunderstorms.

Careful analysis of surface observations south of DPG indicates a very important mesoscale feature. The winds at U24 veered from northwest to north to northeast during the morning and the dew point was steady, holding above 6°C. Between 15Z and 17Z, an apparent boundary moved through as the dew point dropped 5°C and the winds became calm. By 18Z, the winds were 120 degrees at 5 kts and the dew point was 1°C. This was characteristically similar to all other stations south of U24. This dew point discontinuity, best seen on the surface analysis (Fig. 2), is similar to a Southern Plains dryline (in terms of the sharp moisture gradient), which has been known as a preferred region for thunderstorm development (Schaefer 1974). Lightning

data from the Automatic Lightning Detection System (ALDS) (Fig. 5) indicates that this was the zone along which the most active cells originated. As the thunderstorms moved north, away from this original surface convergence region, there was noticeably less organization to the lightning strike pattern (Fig. 6).

Summary

An overview of the storm system indicates that the surface cold front did not act as the initiating low-level convergence mechanism for the severe thunderstorms as it was located north of DPG. However, the dew point discontinuity was in the proper location, passing through Delta but remaining south of DPG. Rapid thunderstorm development occurred in this region at about 19Z, presumably along this dew point gradient. The rest of the atmosphere was primed as well. At 700 mb, a baroclinic band was extrapolated to be over this part of Utah between 18Z and 22Z, enhancing the low-level convergence and, therefore, strengthening the net upward vertical motions.

What appeared to be an inhibitor for good thunderstorm development at Ely's 12Z 500 mb level, i.e, a dew point depression of 15°C, may have acted as a cap, suppressing most convection through midday, until the dynamics and surface heating overcame this negatively buoyant region. This type of dry intrusion, although usually near 700 mb, is often present in the Plains States, where severe weather is more prevalent. Surface observations from DPG support this idea as limited vertical development occurred through the midday hours (except over the highest mountains to the east and far west). By 19Z, though, explosive thunderstorm development ignited between DPG and U24 and moved north. At 1932Z, thunder was heard at DPG, and, by 1955Z, a thunderstorm was in progress at the station. A funnel cloud was sighted at 2015Z, approximately 15 km southwest of the station. Although hail was not reported at the station, 2 cm diameter hail fell to a depth of greater than 5 cm about 11 km west. During the following four hours several funnel clouds, and even a brief tornado (at Hill AFB), were reported.

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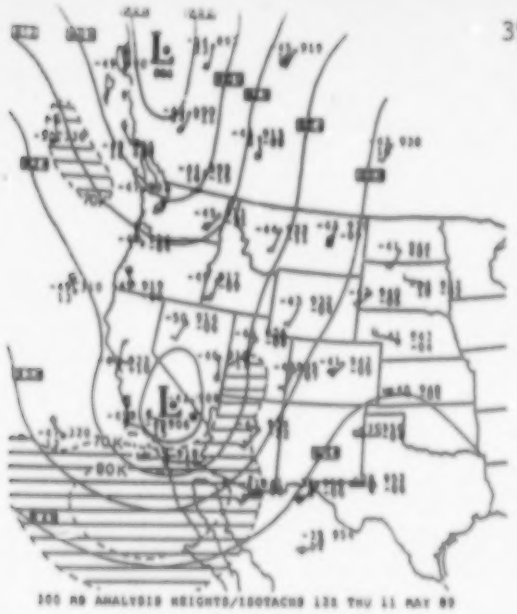
CONCLUSIONS

Thunderstorms in the Great Basin are typically associated with cold fronts or with cold upper-level cut-off lows. Extrapolation of these features normally provides a good first guess at where thunderstorms will occur during the next 12 hours. However, other surface features, discontinuities, or boundaries can play an important role in triggering thunderstorms. These features become increasingly important during the summer months when air mass thunderstorms are prevalent. In this case, the surface convergence was focused around a strong dew point gradient that had the added benefit of strong upper level dynamics moving across it during maximum heating of the day. Therefore, it is important to frequently analyze surface observations in order to capture these subtle mesocale features.



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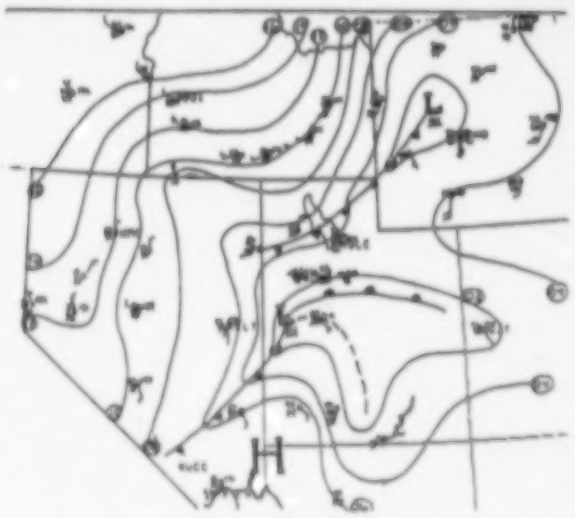

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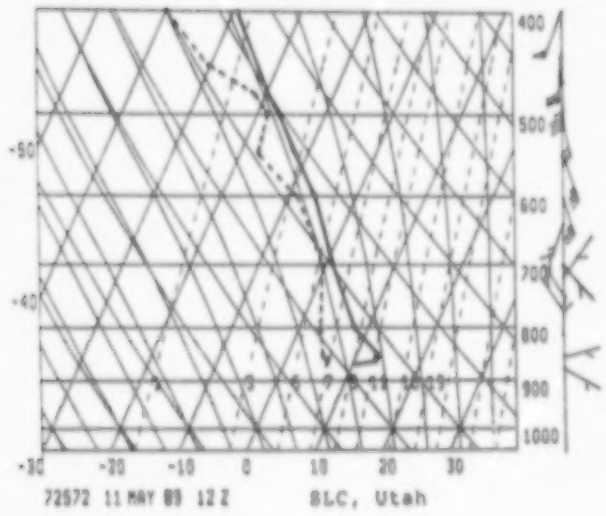

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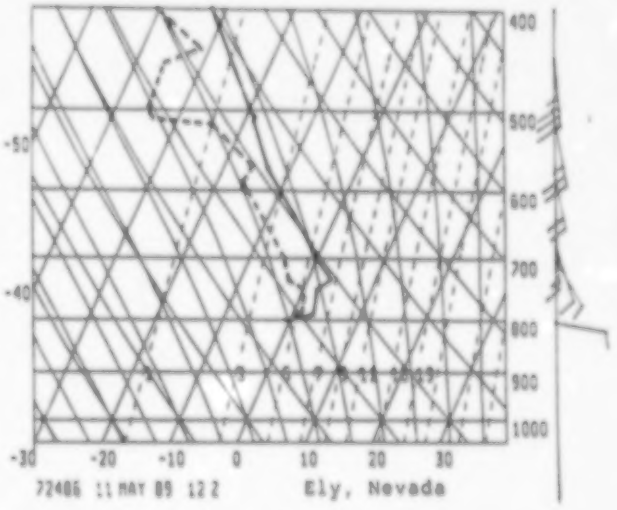

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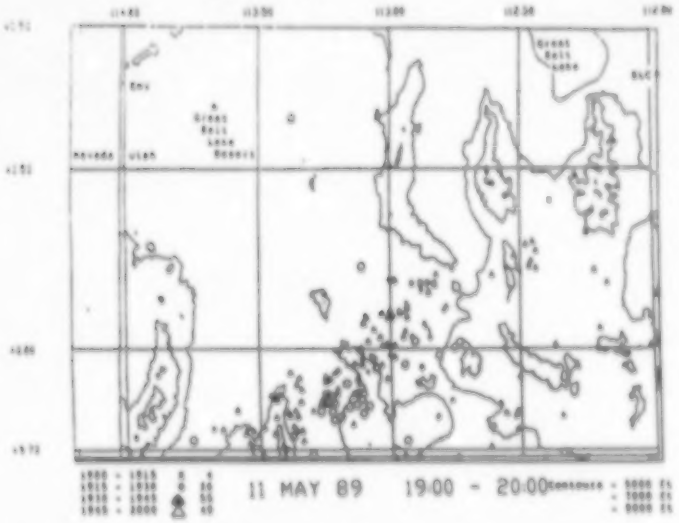


Fig. 5.

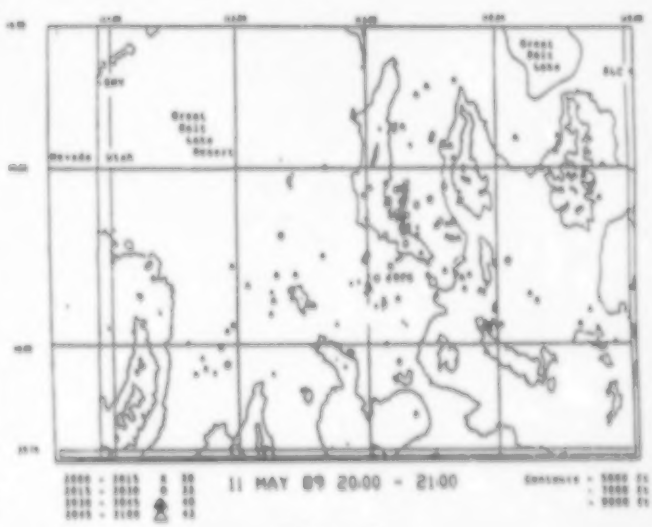


Fig. 6.

THE USEFULNESS OF REAL TIME LIGHTNING DETECTION DATA TO OPERATIONAL FORECASTING

by
Dejan Ristic - Senior Meteorologist
Ontario Weather Centre

Abstract

From April through to the end of November, the Ontario Weather Centre (OWC) leases lightning detection equipment from the Ontario Ministry of Natural Resources (OMNR). This paper will discuss (in broad terms) the available data; current operational use in forecasting; perceived usefulness; and future considerations.

Résumé

Des équipements pour la détection de la foudre du Ministère Ontarien des Ressources Naturelles (OMNR) sont mis à la disposition du Centre Météorologique de l'Ontario (OWC), pour la période d'avril à novembre. Ce document décrit les données disponibles; son utilisation opérationnelle pour la prévision; les avantages de son utilisation; ainsi qu'un aperçu des améliorations futûres.

Background Information

The Ontario Ministry of Natural Resources operates an Ontario wide lightning detection network for its forestry operations from April to September. This network of DF (direction finding) stations is extended to cover all of Ontario south of Bancroft with support from Ontario Hydro and the Atmospheric Environment Service (AES).

The data from this coverage is tapped by outside users...mainly Ontario Hydro and the AES. The AES users are the King City doppler radar site and the Ontario Weather Centre located at the Pearson International Airport in Toronto.

Lightning detection coverage is extended over southern Ontario through to the end of November for the benefit of Ontario Hydro with AES users riding Ontario Hydro coattails. The number of DF stations is reduced to 3 with AES operating King City DF station and Ontario Hydro operating DF stations in Collingwood and Clinton.

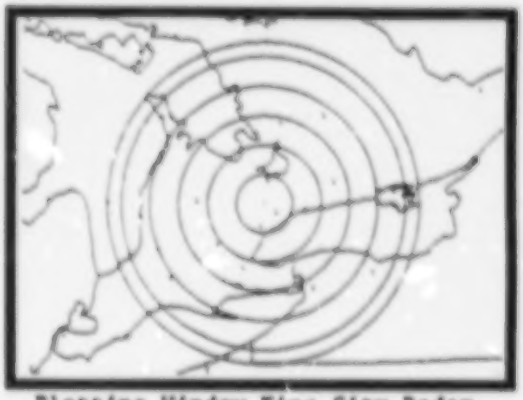
From the beginning of December to the end of March the King City radar site acts as a single DF station which provides accurate direction and timing on lightning strikes but with no information on range.

OMNR operates a commercially produced lightning detection system developed by Lightning Location and Protection Inc of Tucson Arizona (LLP). The system consists of a number of DF stations which sense the electromagnetic fields associated with lightning. These stations process the strength and direction of the lightning signatures and discriminate between cloud to ground versus cloud to cloud strikes. Since the OMNR is strictly concerned with forestry operations only cloud-to-ground discharges are recorded. There are 16 DF stations in Ontario each with an 80% detection efficiency up to a radius of 360 km. The resolution of the sensing antennae are .3 degrees or better and resolution of the system electronics is .2 degrees or better. Filters reject background noises, power

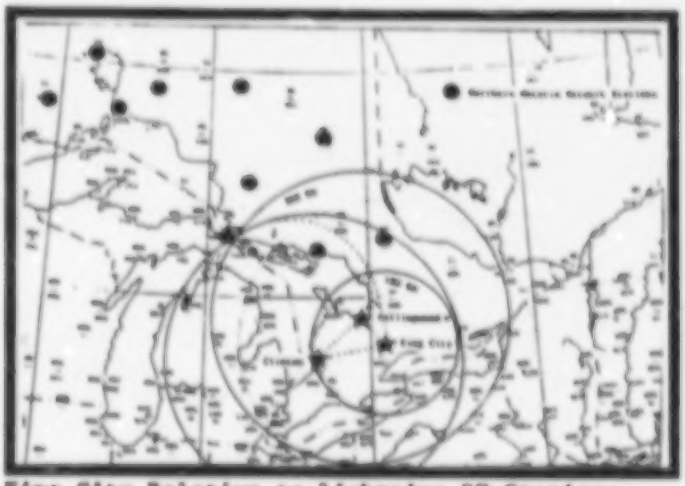
lines, radio and radar transmissions.

The data is digitally sent to a LLP Lightning Position Analyzer Unit (PA) presently located in Sault Ste Marie which processes the DF data mainly by triangulation. The PA unit then permanently stores the data and transmits the times and locations of the strikes to remote data processors that receive and display the data to interested users. The time delay between a lightning strike and data reception at a remote display terminal is effectively negligible.

Full Lightning DF Network Coverage



Plotting Window King City Radar



King City Relative to Lightning DF Stations

Current Operational Lightning Detection Hardware

The OWC has two pieces of equipment for the purposes of lightning detection:

(a) An LLP Remote Data Processor Unit (LLP Model RDP-80-02)
- -displays AP information as a real time lightning map
- -stores up to 25000 flashes allowing replay of lightning data for different maps and time intervals
- -high resolution 8 colour video display allowing real time temporal displays including relevant history with an automatic update feature.

(b) A King City Severe Weather Radar Display Monitor
- the radar site transmits a specific product for severe weather parameters (one of approximately 15 transmitted products). One of items on this display is a 10 minute summary of lightning strikes within the nominal 220 km range of the radar.
- this King City data is obtained via the same AP information line used by the OMNR LLP Model RDP 80-2 described in (a). However the display resolution on the radar monitor is approximately 2 orders of magnitude greater than on the RDP monitor.

Perceived Advantages to Operational Forecasters

1. Effectively the only piece of equipment in the weather centre that displays weather information in instantaneous real time (aside from 'windows' in the office which have a more limited range).

2. The data displayed localizes and highlights a very significant and specific hazard as far as operational meteorology is concerned...namely 'thunderstorms" and 'CBs'.

3. Lightning detection system information...covers data sparse areas...is not affected by topography or bodies of water...is not diurnally affected...and is seasonally independent (as long as someone pays).

4. Lightning data is very useful in correlating convective activity to cloud patterns in satellite imagery (both VIS and IR) and patterns in numerical weather prediction guidance.

5. Data is very simple to understand and independent of level of expertise which is not generally the case with satellite or radar interpretation. Usually means that anyone and everyone in a weather office can glean information from the data. In my OWC experience the lightning display monitor when available has the highest and widest incidence of use.

6. Available colour coded (per unit time) lightning flash density can give reasonable estimates of convective motions and changes in intensity of activity especially with features such as cold fronts, meso-scale convective complexes (MCCs) etc.

7. Lightning detection equipment is relatively inexpensive (in comparison to radar) and currently gives the OWC its best chance for timely and localized summer severe weather warnings to serve Northern Ontario.

Possible Future Improvements

1. At present, a 'hardcopy' of the lightning data product is not available to the OWC. The LLP system is designed for this feature so developing 'hardcopy' on demand is simple to implement.

2. Animation of the lightning flash density in any of several modes would be useful for purposes of timing, determining rate of intensification, and correlation with other OWC data and guidance.

3. Algorithms should be developed to implement latest research, so to develop local correlations of: lightning activity to severe weather; lightning flash rate and density to radar reflectivity and precipitation rates; positive and negative lightning strokes counts to thunderstorm severity and/or intensification (McCann,et.al.,1988). This relatively simple data source has a definite potential to be metamorphosed into useful products for forecasters to improve their skills in meso-scale forecasting for all users.

4. At present the lightning detection network is desensitized to cloud-to-cloud lightning. To the aviation user any lightning aloft is significant. So if AES incorporates a comprehensive lightning detection network then that problem should be corrected.

5. Alert program software could be developed in conjunction with lightning data to alert forecasters when "SIGMETable" thresholds are approached. As well airports within the forecast regions can be plugged into a lightning alert program whereby automatic signals are issued when lightning strikes within 20 km of an airport. This service (given the expanding scope of fibre optics in the communications field) should eventually be offered to all significant airfields and not limited to those airports with weather observing sites.

Conclusion

At the Ontario Weather Centre the lightning detection equipment is considered by most to be very worthwhile and its basic data most useful. Its further potential seems to be significant with some developmental work mainly with respect to software massaging of the data. Obviously there is also room for a significant amount of research. The expansion of the use of this data will benefit the public (especially with respect to summer severe weather forecasting); the aviation industry (with respect to more specific delineations of significant convective activity); and marine interests (especially with respect to squall lines). It is hoped by us at the OWC that our annual 'kowtow' to management just to borrow the equipment will end and that we no longer be required to continually justify our desire for real time lightning data.

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LA MISE EN MARCHÉ DE LA PRÉVISION AGRICOLE

PAUL ANDRÉ RENAUD, service de l'environnement atmosphérique

RÉSUMÉ

Depuis 1987, le service météorologique d'Environnement Canada a renouvellé sa façon de desservir les producteurs agricoles. Auparavant, la prévision agricole avait évolué selon les possibilités opérationnelles du Centre Météorologique du Québec (CMQ) et les besoins pressentis des producteurs agricoles. Le produit reflétait ce que nous pouvions donner à notre clientèle. Le changement initié en 1987 a renversé notre façon de faire. Nous demandons maintenant aux producteurs quel produit ils veulent. Ce changement de mentalité beaucoup plus que de produit a bouleversé nos habitudes de diffusion et notre prise de contact avec le milieu.

Since 1987, the Environnement Canada Weather Services have renewed their approach toward farm interests. Previously, the farm weather forecasts had developed according to the Quebec Meteorological Center's (QMC) operational facilities and the estimated needs of farm interests. The product was then reflecting what could be offered to the users. This entire approach has changed considerably since 1987. Farm interests are now asked to specify their needs. This change of mentality, rather than of product, has made us reorganize our broadcasting practices, along with our approach toward our users.

AVANT PROPOS

Auparavant, on produisait une prévision agricole qui correspondait à la meilleure perception que l'on se faisait des besoins des producteurs et aux moyens les plus faciles que nous avions de la produire et de la distribuer.

Ainsi depuis le début, on avait procédé à quelques changements de la prévision. Changement par exemple, le rajout des degrés-jours de croissance.

Ces changements, comme tous ceux qui se produisent encore, ont dû se plier aux contraintes de l'unité de production, c'est à dire le Centre Météorologique du Québec (CMQ).

Je veux passer en revue le processus de renouvellement de la prévision agricole au cours des dernières années.

Tant au niveau de la recherche de marché que de la production et de la distribution du produit.

LE SERVICE MÉTÉOROLOGIQUE

On peut comparer l'organisation météorologique à une industrie qui intègre verticalement tous les secteurs de l'économie.

Ainsi, l'acquisition des données chez-nous est comparable à l'extraction de la matière première pour l'industrie du secteur primaire.
La production des prévisions équivaut à la transformation de la matière première en usine. Secteur secondaire.
Quant au secteur tertiaire, les bureaux météorologiques jouent le rôle de points de vente au détail ou si on préfère, de réseau de distribution des produits météorologiques.

Au même titre que l'industrie privé, le service météorologique se confronte avec des difficultées analogues de mise en marché.
Pour être efficace il nous faut connaître notre clientèle, savoir ses besoins, et la rejoindre avec les produits qu'elle veut.

Depuis son existance, la prévision agricole a subi des transformations, mais aucune qui soit aussi exhaustive que celle de 1987.

Auparavant, la prévision agricole était constituée de la prévision publique suivie de l'indice d'assèchement.
Puis on y racolait le bloc des aperçus et un dernier bloc, celui de la prévision des degrés-jours de croissance.

Finalement on la distribuait sur les fils de presse, comme la prévision publique.

Constat en 1986

- La prévision agricole est distribuée au compte goutte.
  Sur semaine, Radio Canada la diffuse sur l'heure du midi pour la région de Montréal.
  On répond à la demande dans les bureaux météorologiques.

- On confond souvent la prévision publique avec la prévision agricole. Il manque de distinction entre les deux produits. On dit fréquemment que la prévision agricole n'est qu'une prévision publique avec l'ajout d'indices.

- A cause de cette ressemblance, les prévisionnistes se plaignent de faire de la duplication.

- La radio ne cible pas la population en milieu agricole différemment de celle des villes, ce qui implique qu'elle n'a aucun intérêt à diffuser la prévision agricole. La prévision publique lui suffit.

- La radio trouve le bulletin trop long, et d'aspect rébarbatif. Elle supporte mal des interventions en ondes qui dépassent trente secondes.

Au bout du fil de presse, la prévision agricole tombait dans la poubelle des postes de radio.

Les problèmes de distribution identifiés, cela nous entraînaient vers des problèmes de production.
Quand on sait l'importance des médias radiophoniques pour diffuser un message périssable comme le nôtre, il nous fallait à tout prix leur aide pour rejoindre notre clientèle.

Modification du produit

D'abord, il nous fallait modifier le produit pour répondre aux exigences de la diffusion par la radio.
Et ce, en gardant la satisfaction des besoins de nos producteurs agricoles, comme guide de tout changement.

Pour tenter une meilleure diffusion par la radio, nous avons pensé à des modifications esthétiques.
C'est à dire, une mise en texte plus attrayante et un rehaussement typographique des en-têtes, de même qu'un raccourcissement de la prévision.

Mais qu'allions nous retrancher ?
Pour connaître les besoins des producteurs, nous pouvions nous reposer sur l'expertise de nos gens en agrométéorologie et compulser certaines enquêtes déjà existantes.
Mais nous avons réalisé qu'une enquête approfondie valait la peine d'être entreprise.

Avec l'aide d'un consultant en mise en marché, Chantal Rioux, tous les bureaux météorologiques ont procédé à des interviews téléphoniques d'un échantillon précis de producteurs agricoles.
De la création du questionnaire jusqu'au dépouillement des résultats nous avons suivi une méthodologie impeccable.
Ce qui nous a permis de répondre à toutes les questions qui se sont posées chemin faisant.
Comme par exemple:

- Quels sont les éléments de la prévision que le client priorise ?
- Quels sont les éléments dont il a besoin ?
- A quelles heures veut-il obtenir l'information ?
- Quel média utilise-t-il le plus ?

Nous avons donc concu une prévision pilote qui se démarquait de la prévision publique.
Les paramètres de la prévision étaient ordonnés comme suit:

. La précipitation, avec une probabilité de 5mm ou plus
. L'indice d'assèchement
. Les heures d'ensoleillement
. Vents
. Températures
. Aperçu, à tendance significative. Non pas une lecture de la prévision officielle, mais un résumé à saveur agricole.

Le texte pilote était écrit en pensant à un texte lu en ondes. Non pas littéraire, mais parlé.

Nous en avions éliminé la prévision des degrés-jours de croissance et soigné la mise en page et le rehaussement.

Notre objectif était de rendre la prévision distincte de la prévision publique et suffisamment attrayante pour que d'emblée l'animateur de radio soit intéressé à la mettre en ondes.

Dans les faits, comme dans tout changement j'imagine, ça ne s'est pas passé comme ça.
La contrainte majeure était celle de la production de la prévision.
Le logiciel d'impression de la prévision dans la mémoire de l'ordinateur du Centre Météorologique du Québec ne permettait pas le rehaussement désiré.
Les météorologistes n'avaient pas la formation voulue pour composer des textes radiophoniques, ni le temps de créer un nouveau produit qui n'originait pas de la prévision publique.

Au CMQ on a tenté quand même de s'approcher un peu de la version pilote et surtout de conserver un tout à la prévision agricole et non pas de transmettre uniquement un paquet d'indices agricoles après l'émission de la prévision publique.
On a bougé dans le bon sens et avec la marge que permettait les contraintes techniques et humaines.

Modification de la distribution

Nous n'avons donc pas rencontré notre objectif de diffusion radiophonique par la seule séduction du produit.

Nous avons donc rajusté notre stratégie.
Les bureaux météorologiques ont tous une bonne expertise de la diffusion des prévisions par le biais de médias électroniques.
Et par le fait, de bons contacts avec le milieu.
C'est cette relation symbiotique de nos bureaux avec la radio que nous avons décidé d'exploiter pour percer le champ de la diffusion avec la prévision agricole.
Nous avions en plus, trois antennes Radiométéo Canada à notre disposition et un embryon de réseau de répondeurs téléphoniques pour les producteurs agricoles.

Nous avons donc, pris des ententes avec plusieurs postes de radio. Nous leur avons fournis une présence officielle en ondes, en direct ou en différé. Dans quelques cas où le poste préférait utiliser la voix de ses animateurs, nous avons régulièrement transmis le texte de la prévision selon le nouveau format préparé dans les bureaux météorologiques.

Pour contourner le problème d'emballage du produit et de diffusion à la radio, les bureaux météorologiques ont donc dû assumer la mise en format et assurer directement la mise en ondes radiophoniques.

Bilan

Ces deux dernières années, 45 à 50 postes de radio à travers toute la province ont participé à la diffusion de la prévision agricole.

Nous avons en plus gonflé notre réseau de répondeurs téléphoniques, de quelques unités à onze.
Les lignes téléphoniques de ce réseau sont toutes commanditées à l'extérieur du service.
Nous commanditent:
- le MAPAQ
- l'Union des Producteurs Agricoles (UPA)
- les coopératives agricoles
- le mouvement des caisses DESJARDINS

Pour les saisons 1988 et 1989, ce réseau de répondeurs a livré la prévision agricole à plus de 350,000 demandes à chaque année.
En 1987, nous commencions à nous organiser et avec un réseau de répondeurs embryonnaire, nous avons répondu à 107,000 demandes.

Les postes de radio sont satisfaits de notre collaboration.
D'autant plus que la moitié d'entre eux trouvent des commanditaires pour ces bulletins de météo agricole.

Conclusion

Rapidement, en l'espace d'une saison ou deux, nous avons fortement pénétré le secteur agricole avec notre produit prévisionnel.

Qui plus est, notre volonté de distinguer la prévision agricole et d'en faire un tout complet pour l'utilisateur, nous a fait resserrer les liens avec le réseau d'avertissement phytosanitaire du Québec. Depuis deux ans, nous transmettons les avertissements de ce réseau avec la prévision agricole.
Cette entente avec le Ministère de l'Agriculture des Pêches et de l'Alimentation du Québec pour la diffusion des avertissements a même entraîné une expansion explosive de notre réseau Radiométéo Canada.
Ce qui porte nos antennes à onze à travers le Québec.

La leçon que je tire personnellement de notre démarche en agrométéorologie est claire.

Nous devons nous comporter comme toute compagnie responsable envers sa clientèle.

- Il nous faut répondre à un besoin.
- S'assurer que chaque échelon de notre organisation est sensibilisé par le même objectif.
- Ne négliger aucune étape du cheminement du produit:
  De sa conception jusqu'à sa livraison.

Nous ne sommes pas responsables uniquement de produire des prévisions, mais aussi et surtout de nous assurer que le client les reçoit et en est satisfait.

Chez-nous, aux services météorologiques, c'est la livraison de nos différentes prévisions ou de notre expertise auprès d'une foule d'usagers qui justifie notre existence. Il ne faut jamais l'oublier. Ce sont nos clients qui en ligne de compte payent nos ordinateurs sophistiqués.

Quand trop d'intermédiaires du secteur privé se glisseront entre la production des prévisions et l'usager, nous serons de moins en moins identifiés comme les créateurs du produit et aurons de plus en plus de difficultés à justifier nos budgets.

Nous devons occuper notre place dans le secteur tertiaire de la vente au détail, toute notre place.
C'est la seule façon de bien connaitre les besoins de la clientèle, de contrôler la qualité des services météorologiques qu'elle reçoit, et de nous assurer la visibilité qui nous revient de plein droit.

P.A. Renaud

MÉTHODE DE PRÉVISION DES PRÉCIPITATIONS POUR LE CALCUL DES INDICES CANADIENS FORÊT-MÉTÉO

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ABSTRACT

The Canadian Forest Fire Weather Index System requires precipitation amounts with an accuracy that can be difficult to attain. In this paper, the rain factor is studied within the weather forecast context, by illustrating the accuracy or sensitivity levels which affect the indices forecast computation. A method is proposed to convert rain probabilities into rain amounts parameters required for the index forecasting.

RÉSUMÉ

La méthode de calcul des indices canadiens forêt-météo exige une précision des hauteurs de pluie qui peut être difficile à obtenir. Dans ce présent ouvrage, nous étudions le facteur pluie, dans un contexte de prévision météorologique, en illustrant les niveaux de précision ou de sensibilité qui affectent les calculs de prévision d'indices. On propose une méthode de conversion des probabilités de pluie en paramètres de hauteurs de pluie nécessaires à la prévision des indices.

MÉTHODE DE PRÉVISION DES PRÉCIPITATIONS POUR LE CALCUL DES INDICES CANADIENS FORÊT-MÉTÉO

1. INTRODUCTION

Le Centre météorologique du Québec d'Environnement Canada fournit, par son Service Forêt-météo, la prévision météorologique spécifique pour la protection des forêts contre le feu. La prévision Forêt-météo est une prévision qui tient compte, de façon spéciale, de l'incidence des paramètres prévus (météo et indices) sur le développement potentiel des incendies, sur l'identification des zones menacées et sur la planification des ressources nécessaires aux combats des feux. Il est donc essentiel de connaître les seuils critiques des facteurs météo qui influent sur les calculs des indices utilisés comme prédicteurs des incendies de forêt par les organismes de protection des forêts contre le feu. Dans le calcul des indices canadiens forêt-météo (Van Wagner, 1987), le paramètre PLUIE représente le facteur le plus important dans l'évaluation des teneurs en eau des combustibles forestiers. C'est le seul qui peut abaisser l'indice du combustible disponible (ICD), et il suffit d'une faible quantité de pluie (0,6 mm) pour affecter l'indice d'inflammabilité (ICL). L'ICL, l'ICD et la vitesse du vent permettent d'évaluer les probabilités d'éclosion des incendies de forêt et leur comportement. Dans notre présent ouvrage, nous étudions brièvement le facteur pluie, dans un contexte de prévision météorologique des indices ICL et ICD, en utilisant pour les calculs les équations de la méthode canadienne d'évaluation des dangers d'incendie de forêt (Van Wagner et Pickett, 1985). Nous décrivons par la suite la technique de prévision des précipitations, développée par le service Forêt-météo, pour la prévision de ces indices.

2. FACTEUR PLUIE

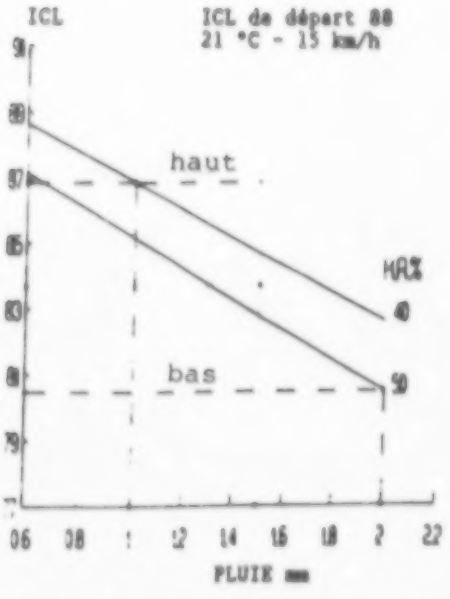

Figure 2.1 Précision du calcul de l'ICL en fonction de la pluie et de l'humidité relative.

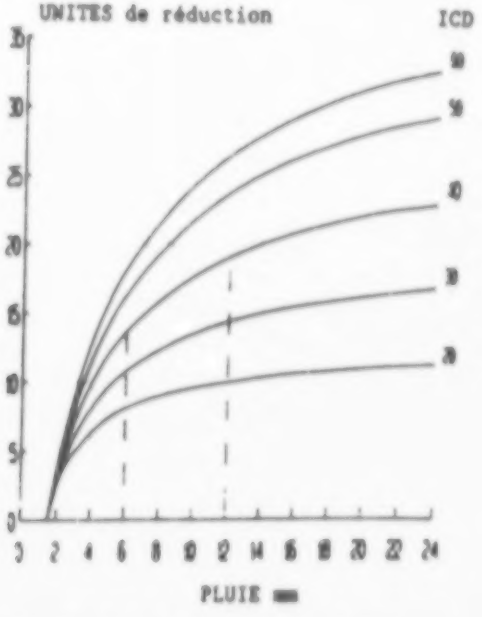

Figure 2.2 Réduction de l'ICD en fonction de la pluie.

En tenant compte des précisions des instruments (± 0,2 mm pour le pluviomètre, ±5% pour le psychromètre), les calculs de l'ICL ne sont précis qu'à ±2 unités (plus ou moins une classe d'inflammabilité). Avoir la capacité d'évaluer à une précision de 0,5 mm les précipitations qui affectent une petite région forestière, disons de 10 km par 10 km, à partir d'un seul pluviomètre situé au centre de cette région, nous semble une précision remarquable. Cependant, l'exemple de la figure 2.1 nous montre que les résultats des calculs d'inflammabilité varieront dans ces conditions de BAS à HAUT. Par conséquent pour la prévision, il est préférable d'évaluer les indices d'une façon spatiale (par zone) plutôt que ponctuelle (par station).

Contrairement à l'ICL, la précision requise pour l'observation de la pluie pour la mesure en général de l'ICD est beaucoup plus facile à obtenir. En se servant des combinaisons (IH et IS) les plus courantes observées durant la saison des feux au Québec, on a calculé pour différents ICD les réductions correspondantes en fonction de la pluie. À la figure 2.2, on voit qu'une réduction d'ICD de 15 unités, à ±5 unités près, pour l'ICD 40, est causée par des précipitations de 4 mm à 14 mm, élargissant ainsi les limites de vérification d'une gamme prévue, disons par exemple, de 6 mm à 12 mm. Le facteur pluie d'environ 7 mm pourrait dans ces conditions permettre d'atteindre une précision de 5 unités pour la prévision de l'ICD; précision largement suffisante pour le calcul de l'indice final, l'IFM.

En étudiant l'effet des différentes hauteurs de pluie dans le calcul des indices, nous nous sommes rendu compte de l'importance relative des précipitations au-delà de certains seuils. Des précipitations de 3 mm permettent d'abaisser l'ICL extrême au niveau NUL ou BAS et de réduire l'ICD d'au moins 5 unités. Après 12 mm, les pentes des courbes de l'ICD s'adoucissent considérablement montrant la faible importance des quantités de pluie excédant cette valeur (voir Turner et Lawson, 1978).

Ainsi, par l'analyse des observations, il est souvent possible d'évaluer l'étendue couverte par des précipitations dépassant un seuil minimum donné qui affecte suffisamment les calculs d'indices, en sachant évidemment que la précision de cette évaluation dépendra de la densité du réseau de stations et aussi des systèmes atmosphériques en cause.

3. PRÉVISION DES PRÉCIPITATIONS

Pour la prévision des précipitations, nous avons suivi le même raisonnement que celui décrit pour l'observation. En fait, nous constatons que c'est un double défi; non seulement il faut déterminer les zones forestières avec pluie, mais aussi les déterminer selon différents seuils de quantité de pluie reliée aux indices. Afin de délimiter des régions de prévisions adaptées à la protection des forêts contre le feu, le Québec a été divisé en quelque 80 zones forestières. Le nombre de zones par région et le nombre de régions formées varient, d'une prévision ou d'une journée à l'autre, selon la complexité des systèmes atmosphériques et selon les besoins de protection particuliers. Pour aider à résoudre le problème des précipitations, nous avons aussi défini des classes de quantités de pluie et avons eu recours aux probabilités.

3.1 Classes de quantités de pluie (QQ)

Les classes de quantités de pluie (ou gammes de hauteurs de pluie) ont été déterminées en tenant compte des seuils des précipitations qui affectent l'ICL et l'ICD. Ces classes sont exprimées en code et ce sont les suivantes:

CLASSES (codes)	QUANTITÉS (QQ)
00	0,1 mm à 0,5 mm
02	0,6 mm à 2,9 mm
05	3,0 mm à 6,0 mm
10	6,1 mm à 12,0 mm
15	12,1 mm et +

3.2 Probabilités

On distingue deux sortes de probabilités: probabilités d'occurrence de pluie (POP) et probabilités qu'une quantité-seuil de précipitations soit atteinte (PP). La probabilité d'occurrence de pluie (POP) permet au prévisionniste d'exprimer, à l'aide de pourcentage, son appréciation des risques de précipitations ou des "chances" d'avoir de la pluie en un point ou sur une région donnée. Lorsque des précipitations sont prévues, la probabilité (PP) s'interprète comme le pourcentage du territoire qui sera touché par la quantité (QQ) de pluie prévue ou le pourcentage de stations qui observeront la gamme la plus représentative de hauteurs de pluie prévue pour une région. Par exemple, on préfère utiliser la gamme 02 pour la prévision d'averses légères ou de bruine, les gammes 10 ou 15 pour les averses modérées, orages, etc. Une probabilité de 50% d'observer la gamme 05 veut dire que cinq stations sur dix signaleront des précipitations de 3 mm à 6 mm. Mais en pratique, on observe plutôt 50% des stations avec plus de 2,9 mm.

De toute façon pour la prévision des indices, le problème n'est pas encore résolu puisque nous avons besoin d'une quantité de pluie (P_i) pour les sous-routines de calcul et non des probabilités. La méthode utilisée durant les saisons 1967 à 1984, pour évaluer le facteur pluie (P_i) pour la prévision des indices, était une méthode subjective basée sur l'expérience et la connaissance des besoins reliés à la détermination des dangers d'incendies. Afin de réduire la subjectivité de la méthode, tout en rendant le produit utile, nous avons cherché une relation objective entre POP, PP et P_i pour déterminer des scénarios de prévision de pluie.

3.3 Scénarios de pluie

L'idéal aurait été, peut-être, de déterminer pour chacune des gammes des probabilités PP et de calculer par la suite l'espérance mathématique (E) des scénarios, à l'aide de l'équation suivante:

$$E(Q_m) = POP \times \sum PP_i QQ_i = P_i.$$

Ainsi on obtiendrait une quantité de pluie P_i qui pourrait être utilisée comme paramètre dans la prévision des indices, lorsque les chances de pluie sont suffisantes. Cependant, l'expérience nous apprend qu'il n'est pas possible de prévoir des probabilités pour chacune des gammes de façon satisfaisante. On peut, par contre, trouver pour une région de protection donnée, les différents scénarios observés en moyenne selon les POP et les PP observées et calculer par la suite les P_i correspondants.

La figure 3.3 montre la courbe exponentielle pour la gamme 05, d'après la compilation des données (796 jours) des saisons 1978 à 1984 d'une des sept régions du Québec, équipée d'un réseau de vingt-quatre stations. Les P_1 calculés correspondaient, en général, à ceux qu'on utilisait auparavant empiriquement lorsqu'on prévoyait cette gamme. Donc, on a pris cette courbe comme modèle pour trouver les P_1 des autres gammes. Des scénarios de pluie ont été développés au moyen des relations trouvées entre les POP et les PP observés et ont été utilisés pour la prévision automatisée d'indices durant la saison 1985.

On retrouve à la figure 3.3A les relations entre le POP (0,6mm) et les PP de 3 mm et 6 mm, donnant des courbes nettement exponentielles (POP≥40), d'après la compilation des données des saisons 1985 à 1988, totalisant près de 2 000 cas ou jours-prévisions. La figure 3.3B montre les scénarios correspondants pour la gamme 05.

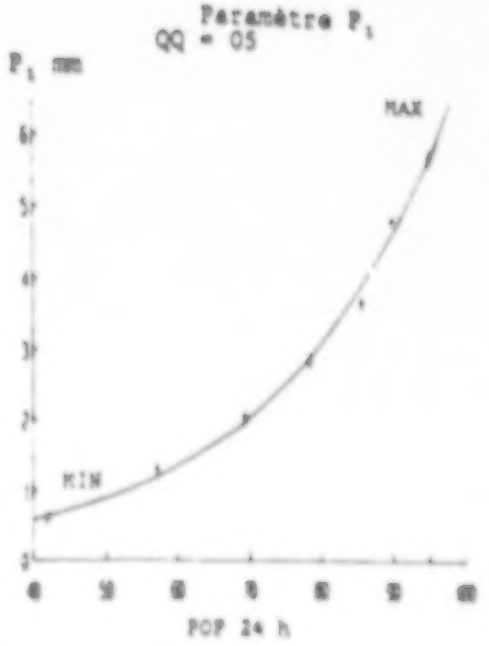

Figure 3.3 Courbe exponentielle des P_1 pour la gamme 05.

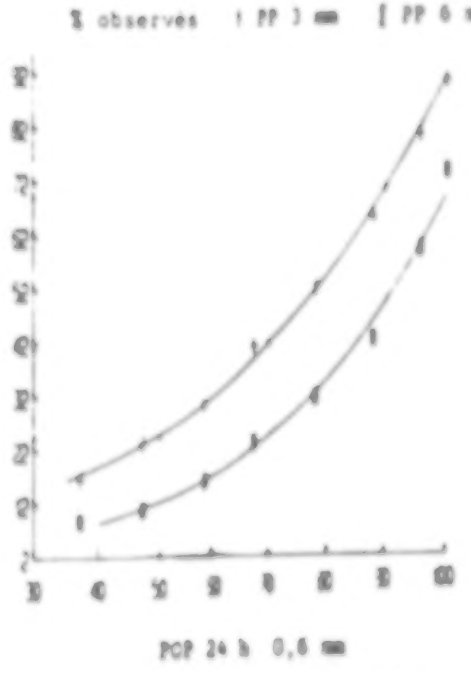

Figure 3.3A Relation POP 0,6 mm - PP 3 mm et 6 mm.

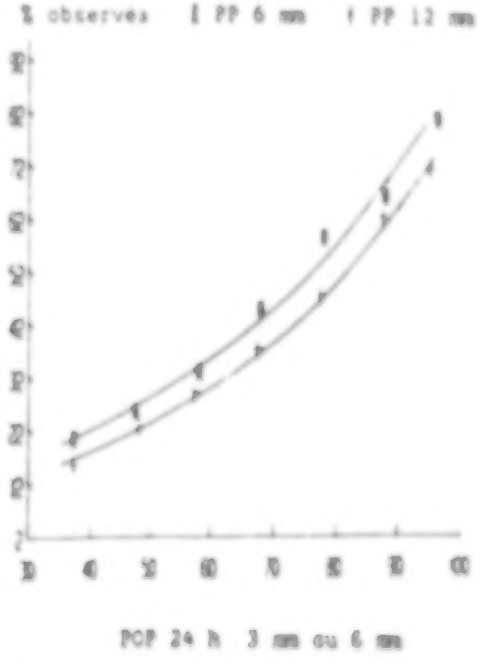

Figure 3.3C POP 3 mm et PP 6 mm
POP 6 mm et PP 12 mm.

POP	QQPP	P_1
10	0510	--
20	0510	--
30	0520	--
40	0520	--
50	0530	1.0
60	0530	1.3
70	0540	2.2
80	0550	3.3
85	0560	4.0
90	0570	5.0
95	0580	6.0

Figure 3.3B Scénarios de pluie pour la gamme 05.

POP	PP	QQ 02	05	10	15
		Paramètre P_1			
00	00	---	---	---	---
10	10	---	---	---	---
20	10	---	---	---	---
30	20	---	---	---	---
40	20	---	---	---	---
50	30	0.5	1.0	2.0	4.0
60	30	0.7	1.5	3.0	6.0
70	40	1.1	2.2	4.5	9.0
80	50	1.6	3.3	6.5	13.0
85	60	2.0	4.5	8.0	16.0
90	70	2.5	5.0	10.0	20.0
95	80	2.9	6.0	12.0	24.0

Figure 3.3D Scénarios de pluie pour les gammes 00-02-05-10-15.

Nous avons choisi le seuil 0,6 mm pour la probabilité d'occurrence de pluie puisque c'est la hauteur minimum de pluie requise pour affecter l'ICL. Mais, il arrive que les systèmes atmosphériques prévus suggèrent plutôt un seuil de 3 mm ou 6 mm et même davantage comme dans les cas d'orages, de précipitations continues et autres. La figure 3.3C montre les relations obtenues entre le POP 3 mm et PP 6 mm, et entre le POP 6mm et PP 12 mm, soulignant ainsi l'analogie des scénarios observés en moyenne des gammes 05, 10 et 15.

Supposant la même relation du POP (trace) avec la gamme 02, nous obtenons quarante-cinq scénarios de pluie pour la prévision des indices de danger de feu, tel qu'illustré à la figure 3.3D. Ainsi, on obtient les P_1 demandés pour les calculs, en déterminant les POP et les classes de pluie (QQ) les plus représentatives, selon les systèmes atmosphériques en cause, la durée ou l'intensité des précipitations prévues.

Cette méthode, en plus d'offrir un moyen très simple et uniforme d'un prévisionniste à l'autre, favorise une meilleure prévision des dangers d'incendie de forêt. Elle permet, en effet, de découper plus finement le territoire forestier en régions de prévision, et d'une façon suffisamment précise pour cerner les zones menacées par des dangers de feux importants et pour discriminer les autres selon les besoins particuliers.

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L'EVOLUTION DES SERVICES METEOROLOGIQUES AUX MEDIAS DU QUEBEC

Guy Borne, Surveillant / Spécialiste en informations météos au Bureau Météorologique de Montréal Dorval, Environnement Canada Service de l'Environnement Atmosphérique.

Ce thème fait apparaitre le rôle prépondérant tenu par les médias dans la diffusion auprès du grand public de bulletins météorologiques émis par le Service de l'Environnement Atmosphérique d'Environnement Canada. Il expose également la priorité et l'importance qu'accorde le S.E.A. à l'amélioration de ses services aux médias.

This topic enhances the primordial importance of the role played by the medias in the distribution to the general public of meteorological information issued by Environment Canada's Atmospheric Environment Service. It also sets forth the importance and the priority given by the A.E.S. for the improvement of its services to the medias.

LE PASSE PAS SI LOINTAIN, L'OBTENTION ET LA DIFFUSION DE L'INFORMATION METEOROLOGIQUE PAR LES MEDIAS.

A) ACCES DES MEDIAS A L'INFORMATION METEO:

Réception de l'information, par telex, fil de presse;
point d'origine: Centre Météorologique du Québec, le C.M.Q.,
la destination: les trois types de médias, presse, radio, télé.
Désavantages; retards, mauvaises réceptions, gribouillages, rejoint les abonnés seulement.

Quête de l'information, par téléphone;
point d'origine, les Bureaux Météorologiques, (à leur création au début des années soixante-dix).
Avantages; contacts personnalisés, raffinement et adaptation de l'information météorologique à l'échelle locale par des spécialistes en informations météorologiques.
Désavantages; à l'origine,ligne téléphonique publique, encombrements et difficultés d'accès, bureaux peu nombreux, localisés à certains aéroports principaux, appels locaux privilégient les médias locaux, médias éloignés pénalisés par les frais d'interurbains. Les bureaux sont peu connus, peu d'appels de médias.

B) LA DIFFUSION DE L'INFORMATION METEO PAR LES MEDIAS:

Constatations;
aucun ou très peu de traitement de base et d'adaptation de l'information météorologique à des versions d'une " souple, élégante, et efficace linguistique radiophonique ", telles celles des sports ou des actualités.

Causes ou raisons?;
aucune formation des médias au traitement de l'information météo. Les contenus des fils de presse étaient très souvent négligés, dédaignés, incompris, mélangés, ridiculisés par certains médias. A la radio, c'était une bouche trou dans la grille des programmes, la météo., cette lanterne rouge de l'information. Le chroniqueur informait plus ou moins son public, à la télé comme à la radio les styles se rapprochaient plus ou moins du réchauffé, au ridicule et à la moquerie. Les journeaux abrégeaient généralement le contenu de la prévision, et ce texte dénaturé était ensuite souvent perdu quelquepart dans la multitude des pages.
Visites éducationnelles ou relationnelles aux B.Ms. quasi-inéxistantes par le personnel des médias. Désinvolture envers les besoins de formation météo. de leurs préposés, ex: Radio-Canada n'accordait qu'une demi ou une journée pour effectuer la " formation " de leurs préposés.
Les B.Ms, ces grands méconnus du grand public et des médias, leur expertise sous utilisée malgré plus tard, l'instauration d'une ligne téléphonique dédiée aux médias. Enfin, absence de la volonté du S.E.A. de rendre le mandat des B.Ms plus visible.

EVEIL DE L'INTERET DU PUBLIC POUR LA METEOROLOGIE.

Entrée en scène de professionnels de la météo du ministère, à la solde de certains médias radio et télé. Ces experts rendent petit à petit l'info. météo. plus disponible, plus comprise, plus crédible etc... au grand public. Je tiens à rendre ici hommage postume à M. A. Ouelette le pionnier de ce genre d'entreprise au Canada Français avec Radio-Canada. Beaucoup l'ont suivi, et plusieurs suivent encore. Ces vedettes de la météo. tel qu'on les étiquettent, ont aussi contribué à, entre autre, développer les aspects sérieux, utiles, et éducatifs de la météo. auprès du grand public.

Les Canadiens en veulent cependant toujours plus et encore mieux et la dite civilisation des loisirs avec le développement d'activités récréatives de masse y est certainement pour beaucoup. Les médias découvrent alors leurs " besoins météo " par des intentions d'expension du produit en quantité et en qualité.

LES REPONSES DU S.E.A.

Contraintes: nous possédons l'expertise, ils possédent le rayonnement, et la visibilité. Que faire pour conjuguer les deux?.

Réponses:
A. Formation des médias.

Journée " porte ouverte aux médias " aux B.Ms. de Dorval et Québec, printemps 1983, les médias invités à découvrir toute la panoplie des services de base que le S.E.A. met à leur disposition. D'autres journées sont tenues par la suite par d'autres B.Ms.

Développement d'un atelier " la météo. et le chroniqueur " au B.M de Dorval, tâche déléguée à R. Fournier, Spécialiste au bureau. Un atelier de deux sessions de quatre heures chacune est structuré. Résultat concluant cela répond aux besoins des médias.

Amélioration de la structure de l'atelier par G. Borne, (2 jours pour un total de 14 heures). Depuis 1984, G. Borne anime deux ateliers par an, et la réponse des médias demeure enthousiaste.

Dans la foulée des ateliers, développement d'un guide de l'animateur pour distribution régionale aux B.Ms. en vue d'animer des ateliers en province, et développement d'un manuel pour les participants.

Développement d'un atelier pour les étudiants en communications du CEGEP de Jonquière se destinant à une carrière médiatique. Cet atelier pourrait éventuellement s'étaler sur 45 heures de sessions théoriques et pratiques. La poursuite des perfectionnements à apporter à ce projet sont la responsabilité conjointe de G. Borne et G. Fillion, des bureaux de Dorval et Québec. Parallèlement, production d'un manuel à l'intention des participants.

B. Formation en communication verbale des spécialistes des B.Ms.

Un stage au CEGEP de Jonquière améliore grandement les talents de communication verbale de la plupart des spécialistes en informations météorologiques.

D'autres stages sont entrepris, et des suivis.

Conscientisation auprès des spécialistes de l'importance, de la priorité, de la qualité des services à donner aux médias, et surtout des progrès individuels à rencontrer chez chaque individu dans le but ultime de mieux servir les médias.

C. Amélioration de l'accès à l'information météorologique par les médias, et revision de nos relations d'affaires et de services

Opérations " courtoisie " sur les lignes téléphoniques exclusives aux médias, nous découvrons entre autre, la nécessité d'accroitre le nombre de lignes réservées aux médias. Ainsi, suivra l'installation à leur intention de répondeurs interactifs multilignes aux B.Ms.

Visites de consultation du personnel des B.Ms. aux principales stations de radio de leur région respective. Un questionnaire sondage leur est présenté afin de pouvoir mieux connaitre et analyser leurs besoins de services auprès du S.E.A.

Participation accrue des spécialistes des B.Ms. lors d'interventions spéciales directes ou différées en ondes. A titre d'exemple accroissement de 171% des interventions en ondes par notre personnel durant les 4 dernières années.

Avènement de l'utilisation du télécopieur à partir des B.Ms pour accélérer la réception dans les salles de nouvelles des alertes et avertissements météorologiques émis par le C.M.Q.

Promotion de Radiométéo Canada, sa découverte par de nombreux médias, et accroissement de son écoute et de son utilisation chez d'autres.

Distribution de récepteurs R.M.C. munis du système d'alerte chez de nombreux médias des zones d'écoute de Québec et Montréal.

Publication d'une revue mensuelle gratuite intitulée Info-météo, bourrée d'articles sur les réalisations du S.E.A. envers les médias, la création de nouveaux services, l'étalage de certains aspects instructifs ou intéressants de la météo, etc...

REALISATION D'UN PROJET DE SERVICE ENTRE LE S.E.A. ET LE RESEAU D'INFORMATIONS " NOUVELLES TELE RADIO " A PARTIR DU BUREAU METEO DE MONTREAL DORVAL.

Le principe: transmission sur une base minimale de quatre fois par jour, de prévisions publiques adaptées à la zone géographique de huit stations radiophoniques du réseau N.T.R. situées dans le sud de la province de Québec, pour un total minimal de trente deux bulletins par jour. A partir du bureau de Dorval, les interventions enregistrées sont acheminées par une ligne de haute fidèlité, puis relayées par satellite jusqu'aux postes de radios. Bien entendu les alertes et les avertissements météorologiques jouissent du traitement prioritaire, lorsque requis.

Le cheminement: printemps 1986, G. Borne parraine le projet; six postes de radios du réseau N.T.R. convoitent nos services avec un enthousiasme bien avoué, ce sont: CJSO-MA de Sorel, CIME-MF de Ste Adèle des Laurentides, CFLV-MA de Valleyfield, CKMB-MF de Montréal, CHEF-MF de Granby, et CKBS-MA de St-Hyacinthe.

Réalisation de l'étude climatologique et topographique de chacune des régions des six stations, avec les incidences météorologiques locales.

Le projet rencontre un succès immédiat, nous répondons à une volonté de la clientèle de disposer de la présence d'experts de la météo sur leurs ondes.

Quatre années plus tard, nous déservons maintenant huit stations du réseau, CIEL-MF de Longueuil, et CHGA-MF de Maniwaki sont venues s'ajouter, CKSM-MA de Shawinigan à remplacé CKMB-MF de Montréal. A plusieurs reprises nous avons dû refuser l'extension de ce service spécialisé à d'autres postes du réseau largement à cause du manque de personnel employé au bureau de Dorval.

LE FUTUR ET LES OBJECTIFS DU S.E.A.

La stabilisation des liens et des réalisations présentes.

La poursuite du développement en communication verbale de notre personnel, et la surveillance de la qualité de leurs interventions.

L'extension du réseau R.M.C. dans plusieurs régions du Québec.

La sensibilisation des médias à diffuser sans délais les bulletins d'avertissements et d'alertes.

L'incitation auprès des médias pour la diffusion des bulletins de prévisions spécialisées, tels la météo agricole, le bulletin des plaisanciers, la prévision marine, etc...

Mener à terme une étude exhaustive de la terminologie météorologique française de nos bulletins. Proposer des changements ou des meilleures utilisations vocabulaires. Vérifier auprès du public, à l'aide d'une firme privée, les propositions de nouvelles terminologies.

La publication d'un manuel de météorologie adaptée aux médias, une sorte de guide pour référence rapide comprenant aussi toute la gamme des services offerts aux médias par le S.E.A. en plus d'un survol de la météorologie théorique.

La poursuite de plusieurs objectifs visant à améliorer nos supports aux médias; exemple: élimination de lacunes dans le service offert par le truchement des fils de presse (Presse Canadienne, Telbec, N.T.R.), retards, délais de retransmissions des bulletins etc... Inciter et aider les services de presse à rendre leurs services d'informations météorologiques plus attrayants pour leurs clients les médias.

CONSTATATIONS

La volonté du S.E.A. de travailler de paire avec les médias est maintenant vieille de près de cinq années, la région du Québec peut être fière du chemin parcouru vers et dans le respect de cette politique. Le public n'a jamais été aussi près de nous, le rayonnement des médias privés d'informations nous à valu d'être mieux connus, mieux appréciés, mieux évalués. L'éveil écologique et la civilisation des loisirs y ont sans doute aussi été pour quelquechose durant ces quelques cinq années. De plus, les sports et la météo sont selon les sondages les deux mamelles préférées de l'auditeur, les jalons sont donc posés, il nous reste à nous faire le devoir de progresser et de s'améliorer dans cette corne d'abondance.

SERVICE A L'AVIATION.

Gilles Sanscartier S.E.A.

Les prévisions météorologiques à l'aviation telles FACN et FTCN n'ont pas subit de changements majeurs depuis plusieurs années. Le FACN (prévision régionale) est souvent complexe et difficile à comprendre, surtout pour le pilote privé qui fait du vol à vue ou encore le plus expérimenté qui n'a pas accès à nos produits de façon régulière. La formation en météorologie de ces derniers laisse également à désirer, les cours dispensés par les écoles de pilotage se limite souvent à quelques heures. Conscient de ces problèmes et désirant améliorer la sécurité en vol, le personnel du bureau météorologique de St-Hubert tente de remédier à la situation avec des produits et un cours de météorologie mieux adaptés aux besoins des pilotes.

Weather forecasts for aviation such as FACN and FTCN have not had any major changes in their presentation for many years. The FACN (area forecast) is often complex and hard to understand, especially for the private pilot who flies visually or the more experienced one who does not have access to our product on a regular basis. The formation given by the flying schools is often limited to a few hours. Fully aware of those problems and wishing to improve the security in flying, the staff of the St-Hubert weather office has come out with products and a course more suitable to the needs of pilots.

FACN1 CWUL
18-06
OTLK 06-18

HGTS ASL UNLESS NOTED
CB TCU AND ACC IMPLY SIG TURBC AND ICG. CB IMPLIES LLWS

PROG

LO 120 NE LA GRANDE IV AT 18Z WITH COLD FNT SWWD THRU JST E CHIBOUGAMAU - JST S VAL D'OR AND WARM FNT SEWD THRU SEPT-ILES.
LO MVG TO NE GOOSE BAY BY 06Z WITH COLD FNT SWWD ALNG STLAWR VLY.
MDT TO STG SWLY FLO PTCHY MOISTURE SE FNT LN. MOIST UNSTBL AIR NR COLD FNT. LGT TO MDT NWLY FLO DRIER NW FNT.

OTTAWA-MONTREAL EASTERN TOWNSHIPS VAL D'OR LAURENTIAN SAGUENAY QUEBEC CITY SEPT-ILES RGNS.

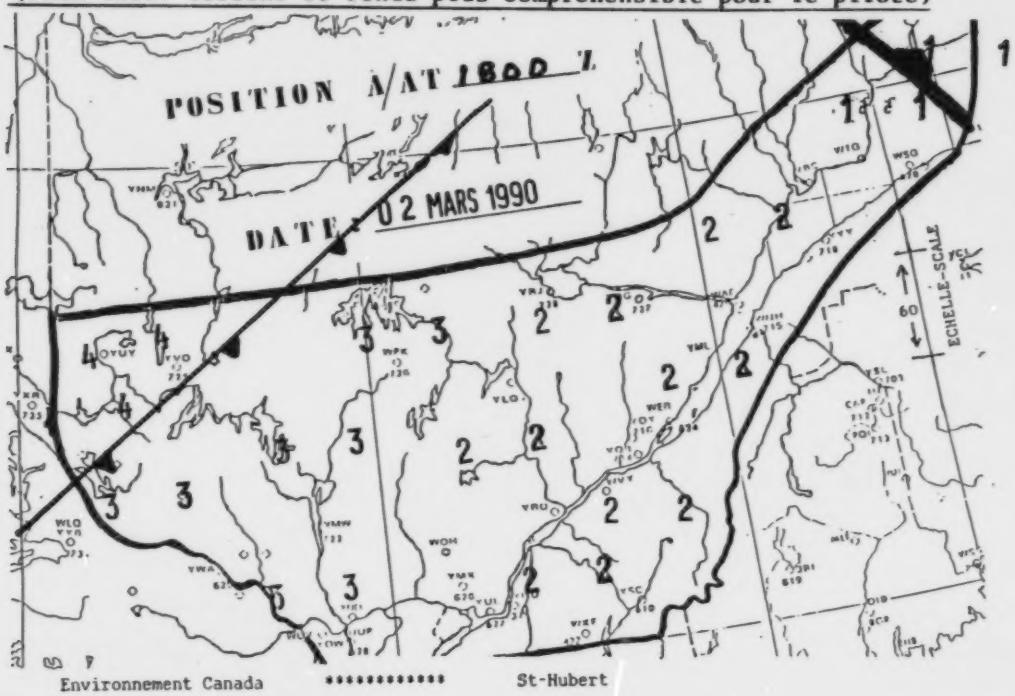
CLDS AND WX.CONDS VCNTY AND NE WARM LN 20 - 30 BKN V OVC 130 /BKN GVG INTMT 2 - 5S- WITH FQT ST AND FOG 6 - 12 HND FT VSBY 1 - 3S-F IN ONSHR FLO. IN WARM SCTR GNLY 40 SCT VRBL BKN LYRS 140 PTCHY /BKN. CONDS BCMG WITHIN 150 NM AHD COLD FNT LN 20 - 30 BKN V OVC LYRS 160 /BKN WITH EMBDD TCU OR ACC 150 GVG OCNL 1/2 - 2SW-/BS AND LCLY ST AND PCPN 3 - 8 HND FT IN PCPN. THE LOWEST CONDS BEING VCNTY FNT LN AND OVR NRN RGNS. CONDS NW COLD FNT 20 - 30 BKN OCNL SCT SC CU 60 PTCHY 70 BKN AC 130 WITH FEW TCU 130 GVG OCNL 1 - 3SW-/BS WITH ST AND PCPN 8 - 15 HND IN PCPN. MOST CVCTV CLDS DSIPTG AFT 02Z AND CONDS GNLY CLR BYD 100 NM NW COLD FNT BY END PD.
WNDS SWLY 25 - 40 KTS IN WARM SCTR SPLY OVR STLAWR VLY.

ICG.LGT TO MDT RIME ICGIC. MDT MXD ICG IN TCU OR ACC. FRLVL FM SFC TO 20 IN WRM SCTR LWRG TO SFC ELSW.
TURBC MDT TO SVR TURBC IN WARM SCTR. MDT TO SVR TURBC IN CVTV CLDS.

OTLK... VFR XCP MVFR TO IFR SW OVR ERN TOWNSHIPS AND OVR S SHR SEPT ILES RGN.

(Voir page suivante pour FACN dessiné)

(FACN CWUL1 dessiné et rendu plus compréhensible pour le pilote)



FACN1 CWUL 021730
18-06
OTLK 06-18

HGTS ASL UNLESS NOTED
CB TCU AND ACC IMPLY SIG TURBC AND ICG. CB IMPLIES LLWS

PROG

LO 120 NE LA GRANDE IV AT 18Z WITH COLD FNT SWWD THRU JST E CHIBOUGAMAU - JST S VAL DOR AND WARM FNT SEWD THRU SEPT ILES.

LO MOVG TO NE GOOSE BAY BY 06Z WITH COLD FNT SWWD ALNG STLAWR VLY.

MDT TO STG SWLY FLO PTCHY MOISTURE SE FNT LN. MOIST UNSTBL AIR NR COLD FNT. LGT TO MDT NWLY FLO DRIER AIR NW FNT

OTTAWA-MONTREAL ERN TOWNSHIPS VAL D OR LAURENTIAN SAGUENAY QUEBEC CITY SEPT-ILES RGNS

CLDS AND WX.

1..... CONDS VCNTY AND NE WARM FNT LN 20 - 30 BKN V OVC 130 /BKN GVG INTMT 2 - 5S- WITH FQT ST AND FOG 6 - 12 HND FT VSBY 1 - 3S-F IN ONSHR FLO.

2..... IN WARM SCTR GNLY 40 SCT VRBL BKN LYRS 140 PTCHY /BKN

3..... CONDS BCMG WITHIN 150 NM AHD COLD FNT LN 20 - 30 BKN V OVC LYRS 160 /BKN WITH EMBDD TCU OR ACC 150 GVG OCNL 1/2 - 2SW-/SWBS AND LCLY ST AND PCPN 3 - 8 HND FT IN PCPN. THE LOWEST CONDS BEING VCNTY FNT LN AND OVR NRN RGNS.

4..... CONDS NW COLD FNT 20 - 30 BKN OCNL SCT SC CU 60 PTCHY 70 BKN AC 130 WITH FEW TCU 130 GVG OCNL 1 - 3SW-BS WITH ST AND PCPN 8 - 15 HND IN PCPN. MOST CVCTV CLDS DSIPTG AFT 02Z AND CONDS GNLY CLR BYD 100 NM NW COLD FNT BY END PD

WNDS SWLY 25 - 40 KTS IN WARM SCTR SPLY OVR STLAWR VLY

ICG. LGT TO MDT RIME ICGIC. MDT MXD ICG IN TCU OR ACC. FRLVL FM SFC TO 20 IN WARM SCTR LWRG TO SFC ELSW

TURBC MDT TO SVR TURBC IN WARM SCTR. MDT TO SVR TURBC IN CVCTV CLDS.

OTLK...VFR XCP MVFR TO IFR SW OVR ERN TOWNSHIPS AND OVR S SHR SEPT ILES RGN

COURS DE METEOROLOGIE
A L'AVIATION

Plan de cours.

OBJECTIFS: Pouvoir utiliser toute l'information disponible pour se déplacer en sécurité.

1 ère période: a) Renseignements généraux.
b) Role et importance des instruments météo dans l'observation météorologique.

2 ème période: Les mouvements de l'air.

3 ème période: Les phénomènes atmosphériques.

4 ème période: Les masses d'air et les fronts.

5 ème période: Les bulletins d'observation.

6 ème période: Les bulletins de prévisions.

7 ème période: Les cartes météorologiques.

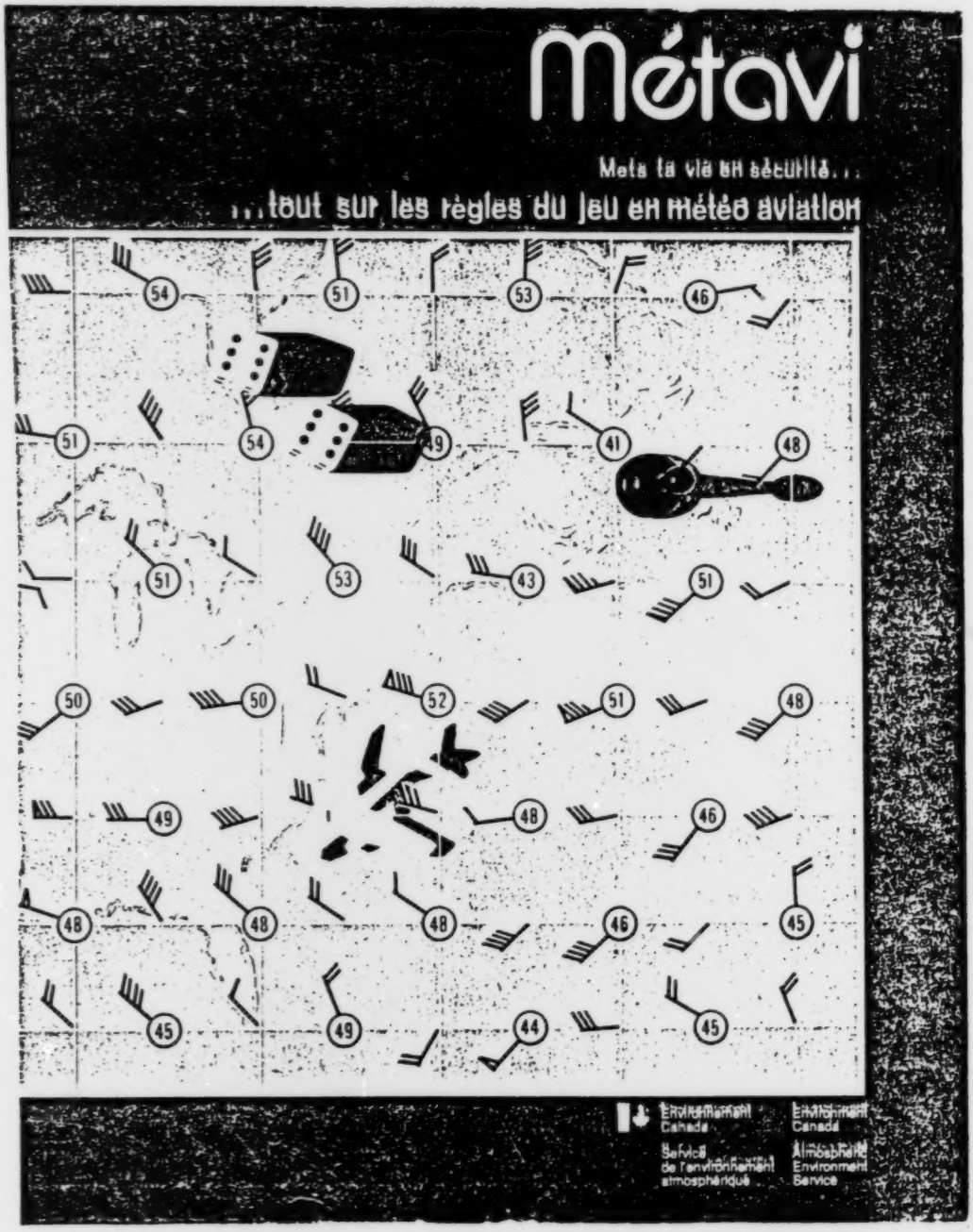
8 ème période: Atelier et cloture.

Durée du cours: 24 heures.

BON COURS

Le manuel "MÉTAVI" a été produit pour le cours de météo aviation destiné au pilote. Dans un premier temps le manuel a été publié en français seulement mais ce dernier a été revisé, corrigé et traduit en anglais. Il sera prochainement réédité, enregistré et mis en vente à travers le pays.

(courverture du manuel)



CONCERNING THE NEED FOR AN EFFECTIVE TRANSFER OF NEW MESOSCALE UNDERSTANDING TO THE OPERATIONAL COMMUNITY

by

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ABSTRACT

The transfer of new understanding of the atmosphere to the operational community is discussed. It is argued that historically this transfer has, for the most part, been accomplished by the development of more accurate NWP and statistical guidance at national centers. A discussion of phenomenological research leads to a suggestion that there could be a more effective way for this transfer to occur. Namely, as new phenomena are observed and understood, there could be an effort by the research community to work with the operational community to develop physically consistent conceptual models that can be used by the field prior to the implementation of successful mesoscale NWP. This would assure the optimal utilization of new data sources from their inception.

Le transfert de nouvelles connaissances à la communauté opérationnelle est abordé. Historiquement, ce transfert s'est opéré , en grande partie, par le développement de modèles numériques et statistiques plus précis. Une discussion sur la recherche suggère que ce transfert pourrait se faire plus efficacement. Quand un nouveau phénomène est observé puis compris, la communauté scientifique devrait s'efforcer de travailler avec la communauté d'exploitation afin de développer des modèles conceptuels physiquement cohérents qui peuvent être utilisés en opération avant l'arrivée de modèles numériques à mésoéchelle qui soient adéquats. Ainsi on s'assurerait d'une utilisation optimale de nouvelles connaissances dès le début.

INTRODUCTION

Over the last 20 years or so, great advances have been made in the accuracy of numerical weather prediction, at least for synoptic-scale dynamics. As the operational numerical models have improved over the years there has been less and less room for subjective improvement over the objective guidance. It can be argued that the numerical models have advanced to the point that we are approaching a limit in forecast accuracy that is dictated by our operational data network, making subjective improvements by the field forecaster more and more difficult. This trend has provided some with the basis to argue that the time is near to remove the operational meteorologist from the forecast process, and have him/her there only as a monitor. Yet, we are about to enter a new era of observing capabilities, and it is argued here that given the proper tools forecasters will once again be able to make substantive improvements over objective guidance.

In this paper the process of technology transfer is discussed, both how it has worked in the past and how it could work in the future; geophysical phenomenological research is also discussed in this context. Finally, a proposed sequence for the effective transfer of new mesoscale understanding to the operational community is described. An emphasis of this sequence is the joint development of diagnostic and prognostic conceptual models for use in operations prior to the successful development of operational, mesoscale NWP.

TECHNOLOGY TRANSFER

Gains in forecasting accuracy have been achieved through a seesaw of gains in observations and understanding. Gains in observations have been achieved in two ways (1) implementation of new operational instrumentation (e.g., radiosonde, radar, and satellite), and (2) special field programs (Doppler radar, higher frequency data collection, etc.). Gains in our fundamental understanding of the atmosphere have been achieved through work in both the analytical and numerical arenas.

These forecasting gains have been achieved with efforts from both the research community (including national centers) and field forecasters. The research community has contributed mainly through improvements in NWP, statistical guidance, and some descriptive conceptual models; while the field forecasters have applied their excellent observing capabilities to the development of in-house conceptual models and boot-strapping local techniques. All in all this has been a rather slow process; most of the transfer has taken place through objective guidance products (NWP and statistical) and not through direct communication and collaboration.

There are at least two reasons why this transfer has not been more efficient. The first deals with the way the research community views the forecast problem. The majority of researchers feel that if they present a descriptive, non-technical case study, elucidating the salient features of a certain phenomenon the transfer process has been successful. This attitude ignores the necessary, sufficient, and antecedent conditions that are all needed for application in the field. A medical analogy is that given you have tuberculosis there is a very high probability that you will have a cough (the research case study), yet you certainly don't want to diagnose all people with coughs to have tuberculosis (the forecast problem)! (personal communication, K. Hammond, Univ. of Colorado.)

The second problem is on the operational side. Most forecasters are unable to keep up with advances in meteorology due to scheduling and the lack of effective training efforts (at least in the United States). This deficiency contributes to the local development of physically inconsistent or unrealistic conceptual models that typically do not handle the forecast situation as well as is possible. Examples of this will be given at the conference.

GEOPHYSICAL PHENOMENOLOGICAL RESEARCH

Dr. Fletcher, the Director of the United States Environmental Research Laboratories, recently talked about the direction of research within our Laboratories. In this talk he identified five steps associated with geophysical phenomenological research: namely, (1) observe, (2) understand, (3) predict, (4) assess, and (5) control. The first three of these are related to how our weather services function. In order to successfully predict a phenomenon we first need to be able to observe and understand that phenomenon.

For the first time, with the installation of profilers and Doppler radars, we will be routinely observing phenomena on the mesoscale (step 1) and the research community is already working to understand them (step 2). How do we best accomplish step 3? If we allow history to repeat itself a great deal of this new understanding will not be effectively transferred until accurate mesoscale numerical models are developed; this will likely be 15 y or more before models are routinely run at, say, 5 km resolution. This leaves the field forecaster to deal with these new phenomena that he or she will see routinely. This will result in a renewed effort at the field offices to develop new forecasting techniques and conceptual models. Can't some of the new understanding be transferred to operations prior to NWP?

PROPOSED SEQUENCE FOR THE MOST EFFECTIVE TRANSFER

Just as there is a logical sequence for phenomenological research, there should be one for technology transfer. Here is a possibility, (1) improve observations, (2) increase

understanding of phenomena, (3) develop scientifically sound diagnostic and prognostic models, and (4) improve numerical weather prediction. This sequence encourages immediate transfer of new understanding to the field forecaster through the development of conceptual models. The research community should be encouraged to be involved in the development of these conceptual models to assure their physical consistency. This is particularly important since these models are known to be the best way for the forecaster to assimilate vast amounts of data. Then, as NWP improves, these models will evolve into prognostic conceptual models that can be used to evaluate the realism of objective guidance.

SUMMARY

We are about to enter a new era (dictated by new observing capabilities) that will provide the field forecaster with a whole new gamut of phenomena to identify and predict. The onus is now on the research community to work with the operational community and develop the most physically realistic conceptual models (both diagnostic and prognostic) that our understanding allows. These models will provide the field forecaster the tools necessary to effectively deal with these phenomena. In concert with this effort, ongoing numerical and statistical developments will also feed into more accurate mesoscale forecasts through objective guidance.

BRIDGING THE GAP - THE IMPLEMENTATION OF RESEARCH

By

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Abstract

The paper looks at the phases a project goes through between being conception and a fully maintained operational system. It discusses options at each stage and recommends procedures that will increase the likelihood of success. It reviews the roles of the client or operational arm and that of the research and development unit at each phase of the project, again recommending who should play what part. Finally, the paper concludes with a review of the major pitfalls to avoid in this type of project.

Résumé

Cet article examine les différentes phases d'un projet depuis sa conception jusqu'à l'obtention d'un sytème opérationnel complet. Il inclut une discussion des options possibles à chaque étape et fait des recommandations sur les procédures qui agmentent les chances de succès. Les rôles de l'utilisateur et de l'unité de recherche et développement sont examinés pour chaque étape d'un projet et des recommandations sont aussi faites à ce sujet. Finalement, les principales embûches à éviter dans ce genre de projet sont mentionnées.

I N T R O D U C T I O N

Moving a project through its various phases towards eventual implementation into operations is neither easy nor even guaranteed to work. Many projects never reach operational status. Many fail because they weren't very good ideas in the first place, but many good ideas either fail or are seriously delayed due to the key players not fully understanding the others situation. This is frequently compounded by the mis-allocation of responsibilities in various stages and the choice of inappropriate development strategies.

This paper will discuss the project phases in taking a recognized problem through research and development to implementation. It is important to note that this strategy does not necessarily apply to other classes of projects (e.g. replacements, simple extensions to existing functionality).

In the following, the term Operations is used to represent the organizational unit who will be the eventual users, the term Research is used to represent the organizational unit normally tasked with developing tools and techniques for Operations.

The phases and the roles of the main players are suggestions only, based on several years of experience and of observation of projects in other organizations.

PROJECT PHASES

Recognition and Hypothesis Testing Phase

A project can be initiated in several ways. One way is the Recognition of an opportunity to solve an existing problem. This type of project initiation is somewhat fortuitous. Someone or some group must be aware of new or emerging techniques and technologies, and be aware of a range of unsolved problems in Operations. In addition, this person or group must hypothesize the applicability between the technology and the problem and be sufficiently resourced to test the hypothesis.

In this case either Operations or Research could recognize the opportunity and formulate a hypothetical solution. It is more likely that only Research will be in a position to test the hypotheses.

The second scenario of project initiation occurs when a problem suddenly appears and requires the application of existing techniques for solution. This scenario encompasses a large number of projects, usually requiring less resources but requiring rapid solutions.

In this case Operations recognizes the problem and, due to time constraints, almost always solves it as well.

A third class of projects are initiated when a problem appears but no existing techniques or technologies are applicable. This class of project are even more difficult to bring to completion. Here, resources must be expended to simply find the applicable technology, without any certainty that one exists.

In this high risk scenario, Operations again identifies the problem but it is most likely that only Research will be sufficiently resourced to undertake the project and even they will be stretched.

A final class of projects unfortunately exists. These are the projects where a technology or technique is applied to an area where no real problem exists. In this case, the project is clearly doomed, no amount of good project management will help the end result.

In evaluating a current or proposed project, it is wise to ascertain into which of the above categories it falls and the degree to which Operations and Research play their roles.

In what follows, the simpler case of Operations having stated a problem and Research having successfully tested the applicability of a technology.

Development Phase

Once a successful merger of problem and technology has been established, working prototypes must be developed. It is becoming obvious in this type of project that rapid prototyping is a much more successful approach than the traditional top-down design with User Requirements, System Specifications, etc.

In new product development, the statement of User Requirements is a difficult and inefficient process for the user. Generally the User simply doesn't know what his requirements for a new product are. It is much simpler for the User to evaluate an initial prototype, saying what they like and dislike, wait for another prototype and repeat the procedure.

From the developer's viewpoint having a weakly justified set of User Requirements from the beginning is unnecessarily restrictive. It usually prevents experimentation with new approaches and can focus undue amounts of time on areas that will later require change anyway.

Management can be uncomfortable with approving an open-ended prototype development path vs. more traditional EDP practices. On paper it is easier to see when a project will be completed assuming only one pass through Requirements, Design, Development, Testing, Implementation and Training. However, if we have learned one thing in the past decade it should be that that path is almost certain to lead to project overruns. In fact, the iterative, open-ended prototypical approach will almost certainly lead to a usable product sooner.

For the type of project under discussion here, a prototyping approach is highly recommended. Ultimate and interim user satisfaction is much more likely to result.

User Education and Operational Implementation Phase

Eventually, a decision will be made to stop prototyping and deliver an operational system. It might not be clear at which point the switch-over comes, it may be more influenced by external factors than anything intrinsic to the project.

It is important for several reasons that once this decision is made that Research rid themselves of the project lead ASAP. First, Research has no control of the operational support systems with which this system must be integrated. This can lead to problems when a change in the support systems is required. Second, Research must stop developing if there ever is to be a sufficiently stable version to implement. Third, Research doesn't do a very good job of implementing. By the nature of the group, developing turn-key operational systems is probably something quite foreign to them. Lastly, Operations will sooner or later have to take responsibility for the system and a handover at this stage is most logical.

The decision to develop an operational system implies the decision to conduct user training. There will be a larger group of users than have been involved in the prototype testing and they must be trained or at least exposed to the scientific bases of the new system. In addition, turnover of staff in Operations is quite rapid and new users will be coming on stream rapidly. User training is best led by Research, but should involve those parts of Operations involved in the prototype development and should be conducted in consultation with professional training advisors.

Upgrade and Maintenance Phase

Once an operational system is in place, the question of who handles bug fixes, upgrades to the system, changes required by upgrades to the supporting systems etc. must be answered.

It is clear from our experience and it should be clear from the preceding sections that Operations must take the lead in this activity. There are two main reasons for this. Firstly, Research tends to be too dependent on the individual scientist or scientists that undertook the development. Relying on those individuals for ongoing maintenance is clearly foolish.

Secondly, Research must be allowed to move on to develop future versions of this system or attack other project areas. If research and maintenance compete for resources from the same organizational unit, maintenance will always win because if its urgency. However, the resultant loss of research time will ultimately prove to be more costly.

S U M M A R Y

To summarize the advice for someone charged with ensuring a project moves through to operational implementation:

Recognition and Hypothesis Testing Phase - Ascertain the category of the project. Ensure there is a problem to be solved.

Development Phase - Use rapid prototyping.

User Education and Operational Implementation Phase - Turn the project over to Operations as early as possible in this phase. Ensure User Education is planned and takes place.

Upgrade and Maintenance Phase - Ensure there is a home in Operations for this responsibility.

Instabilité symétrique: Interprétation physique dans un contexte opérationnel

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Résumé. Une revue de littérature sera faite à propos de l'instabilité symétrique et de son rôle sur la structure des zones de précipitations. Une interprétation physique de ce concept sera présentée. Nous discuterons de l'utilité ainsi que de la faisabilité d'introduire ce nouveau concept dans le milieu opérationnel à l'aube de l'ère des Bureaux de Service Météorologiques et de l'importance accordée aux prévisions des phénomènes d'échelle moyenne.

Abstract. A review on symetric instability along with its role on the internal structure of precipitation area will be presented. An attempt will be made to give an operational physical interpretation of that concept. Usefulness and feasibility of introducing conditional symetric instability analysis in an operational environment such as the Weather Services Office will be discussed.

1. INTRODUCTION.

L'introduction des radars météorologiques ainsi que l'amélioration des réseaux d'observations de surface a fortement contribuée à raffiner les modèles conceptuels sur la structure des zones de précipitations. Plusieurs auteurs dont ***Browning et al. (1973) et Hobbs (1978)*** ont montré que les structures de précipitations en bandes étaient la règle plutôt que l'exception. Les données d'un pluviomètre à auget basculant montrent des variations d'intensité de précipitations remarquables confirmant également l'existence de bandes de précipitations.

Plusieurs mécanismes ont été avancés pour expliquer la structure des bandes de précipitations dont le mouvement vertical associé aux zones frontales (incluant ou excluant la présence d'ondes de gravité), le soulèvement orographique et les flux de chaleur et d'humidité dans la couche limite. ***Seltzer et al. (1985)*** ont documenté plusieurs cas où les bandes de précipitations étaient éloignées des zones de soulèvement frontale ainsi que de zones de flux de chaleur émanant de la surface. ***Bennets et Hoskins (1979)*** ainsi qu'***Emanuel (1979)*** ont démontré que l'instabilité symétrique conditionnelle (convection inclinée) favorisait la formation de bandes d'instabilité sous forme de lignes. ***Emanuel (1988)*** avec des résultats de l'expérience GALE et ***Reuter et Yau (1990)*** avec des observations de l'expérience CASP ont montré que l'atmosphère lors de tempêtes hivernales était stable par rapport à la convection verticale, mais neutre ou légèrement instable par rapport à la convection inclinée. Dans tous les cas étudiés, la présence de bandes de précipitations a été documentée.

Avec l'avènement du plan stratégique et l'emphase mise sur la prévision régionale à courte échéance, les centres météorologiques doivent avoir la capacité de prévoir à moyen terme si l'atmosphère sera favorable à l'apparition de bandes de précipitations et de prévoir leurs déplacements à courte échéance à l'aide des radars météorologiques.

Cette note se veut une revision du concept de stabilité symétrique et de convection inclinée par rapport à l'évaluation classique de la convection verticale. Une interprétation physique de la convection inclinée sera faite. L'évaluation de la convection inclinee dans le contexte actuel et futur sera également discutée.

2. STABILITE SYMETRIQUE ET CONVECTION INCLINEE.

Discutons d'abord du phénomène d'instabilité inertielle (cas particulier de l'instabilité hydrodynamique à deux dimensions) qui se produit dans un écoulement. On sait que les mouvements d'un fluide sont stabilisés par la rotation au même titre qu'ils le sont par une stratification stable de la flottabilité (buoyant force). Ainsi, le champ de pression dans un équilibre cyclostrophique ou géostrophique tend à retourner la particule déplacée à sa position originale. Le même phénomène se produit lorsque l'on déplace verticalement une particule d'air dont la température est plus froide que son environnement. Considérons un écoulement zonal en équilibre géostrophique avec un gradient de pression nord-sud

$$\bar{u}_g = -\frac{1}{\rho f}\frac{\partial \bar{p}}{\partial y}$$

et imaginons un tube de fluide le long de l'axe est-ouest pouvant se déplacer latéralement. Une approximation locale du moment angulaire absolu peut-être écrite sous la forme

$$M = u_g - fy$$

(voir *Holton (1979) p.16* ainsi que *Lilly (1986) p.261*). Le moment angulaire absolu est conservé dans le plan tangent aux équations de mouvement. Ainsi, un tube de fluide déplacé vers le nord augmente sa vitesse zonale par f fois son déplacement car par conservation du moment angulaire on obtient

$$\frac{dM}{dt} = \frac{d\bar{u}_g}{dt} - f\bar{v}_g \equiv 0$$

Si le gradient de pression ne s'ajuste pas à cette augmentation de vitesse, le tube devient supergéostrophique et retournera à sa position initiale telle que montré par la composante y de l'équation du mouvement horizontale

$$\frac{dv}{dt} = f(u_g - u)$$

Ceci veut dire qu'un écoulement dont la composante nord du cisaillement est inférieure à f est stable aux déplacements horizontaux. Si on généralise ce résultat à deux dimensions, on obtient la condition de stabilité inertielle pour l'hémisphère nord sous la forme

$$f + \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y} = f_{abs} > 0$$

et qui dit tout simplement que la composante verticale du tourbillon absolue doit être plus grande que zéro. Si cette condition n'est pas respectée (ce qui peut arriver localement), l'atmosphère réagit très rapidement et s'ajuste par un mécanisme de mélange turbulent dont on croit qu'il est responsable de la turbulence en air clair.

Dans le cas d'un écoulement en équilibre hydrostatique et géostrophique avec du cisaillement dans la verticale ainsi que dans l'horizontale, les effets de la flottabilité et de la rotation combinés nous mènent vers un autre type d'instabilité. On suppose que l'écoulement considéré (champ de hauteur) ainsi que le champ de température potentielle respecte l'équation du vent thermique

$$f\frac{\partial \bar{u}}{\partial z} = -\frac{g}{\theta_0}\frac{\partial \bar{\theta}}{\partial y}$$

La figure 1 (adaptée de *Lilly (1986)*) montre des isolignes de température potentielle et de moment angulaire absolu (composante locale selon x puisque l'on considère un écoulement zonal)

$$M = u_g - fy$$

Dans une atmosphère idéale, ces deux quantités diminuent vers le nord et augmentent en altitude (dans l'hémisphère nord). Si notre tube de fluide se déplace du point A au point B, il aura une température potentielle supérieure à celle de l'environnement en B et un moment angulaire inférieure. Le tube possède donc une flottabilité positive et, puisque qu'il est sousgéostrophique par rapport à l'environnement, va accélérer vers le nord. Une analyse de la figure 1 nous indique qu'il y

aura instabilité chaque fois que les isolignes de température potentielle auront une pente supérieure aux isolignes de moment angulaire. Mathématiquement, nous avons les conditions suivantes

$$\left.\frac{\partial z}{\partial y}\right|_{\bar{\theta}} > \left.\frac{\partial z}{\partial y}\right|_{\bar{A}} \quad \text{(instabilité)}$$

$$\left.\frac{\partial z}{\partial y}\right|_{\bar{\theta}} < \left.\frac{\partial z}{\partial y}\right|_{\bar{A}} \quad \text{(stabilité)}$$

Il est possible de retravailler l'expression qui montre la condition de stabilité (la seconde) en appliquant la règle de dérivation en chaine et en exécutant quelques manipulations algébriques pour obtenir

$$\frac{N^2}{(\partial \bar{u}/\partial y)^2}\left(1 - \frac{2\bar{u}/2y}{f}\right) > 1$$

Le premier terme de gauche est le nombre de Richardson. Si on néglige le cisaillement latéral, la condition de stabilité se réduit à ce que le nombre de Richardson soit plus grand que 1.

Jusqu'à présent, nous avons négligé les effets de la condensation. ***Bennetts et Hoskins (1979)*** ainsi qu'***Emanuel (1983 a,b)*** ont tenu compte des effets déstabilisateurs du dégagement de chaleur latente de condensation pour convertir le problème d'instabilité symétrique en un problème d'instabilité symétrique conditionnelle (ISC). L'addition de la chaleur latente complique grandement la problématique. Pour contourner cette difficulté, les données sont recueillies le long de ligne de moment angulaire constant. L'argumentation justifiant une telle approche est faite dans ***Emanuel (1983a,b)***. Si une particule est en ascendance le long d'une surface constante de moment angulaire, elle atteindra son point de saturation et deviendra plus chaude que son environnement. Les conditions d'instabilité symétriques auront été rencontrées. On parlera donc de convection inclinée. On trouvera dans la littérature de nombreuses études de cas comparant la convection verticale et inclinée (***Emanuel, 1983b; Sanders et Bosart, 1985; Seltzer et al., 1985; Sanders, 1986; Reuter et Yau, 1990***).

3. INTERPRETATION PHYSIQUE DE LA CONVECTION INCLINEE.

Les outils opérationnels, jusqu'à récemment, permettaient peu de flexibilité dans l'analyse du déplacement des particules. L'utilisation des surfaces isentropiques s'est soldée par des succès limitées. Il est évident que les particules dans l'atmosphère se déplacent selon des plans inclinés en particulier à proximité des zones frontales et des dépressions en phase de creusage. Le modèle conceptuel de ***Browning (1971)*** et de ***Carlson (1980)*** ainsi que la simulation de la tempête 'President's Day' par ***Uccellini et al. (1989)*** nous montrent bien le rôle des ceintures d'écoulement ainsi que la présence possible de convection inclinée.

D'une façon dynamique, les instabilités inertielle, symétrique et convective sont reliées car elles se produisent à cause d'une distribution instable de forces agissant sur le fluide. Dans le cas de la convection, la force responsable est le gravité agissant selon la verticale alors que dans le cas de l'instabilité inertielle il s'agit de la force centrifuge qui agit selon la perpendiculaire au mouvement (force radiale). L'instabilité symétrique représente une combinaison des deux effets. Cette combinaison entraine donc de la convection inclinée.

Physiquement, il s'agit donc d'une façon de représenter les caractéristiques thermodynamiques d'une particule selon le plan (incliné) sur lequel elle s'élève. Si le plan inclinée que l'on choisit pour représenter les caractéristiques thermodynamiques de la particule est un plan de moment angulaire constant,

l'énergie potentielle disponible par la convection inclinée (Slantwise Convective Available Potential Energy ou SCAPE) sera maximale (ce résultat important est dérivé et discuté dans *Emanuel, 1983b*).

4. EVALUATION OPERATIONNELLE DE LA CONVECTION INCLINEE.

La méthode la plus directe pour évaluer l'ISC serait de mesurer la température et l'humidité le long d'une surface M=constante en utilisant un avion instrumenté. Evidemment, cette démarche n'est opérationnelle que lors d'expérience sur le terrain comme ce fut la cas lors de CASP, GALE et ERICA.

Puisque des sondages sont faits deux fois par jour sur une base opérationnelle, on peut les utiliser pour évaluer l'énergie potentielle totale disponible pour la convection inclinée. Le ballon ne s'élève pas le long d'une surface M à cause de sa dérive horizontale. La façon la plus simple d'utiliser les ballons consiste donc à construire des coupes verticales à l'aide de deux ou plusieurs sondages alignés perpendiculairement au cisaillement géostrophique dont la direction (au-dessus de la couche de mélange) est donnée par le vent thermique. Puisque la distance horizontale entre les stations de sondages est connue, M peut-être estimé à partir de la composante de l'écoulement géostrophique perpendiculaire à l'axe de la coupe verticale. Les surfaces M=constante peuvent donc être construites. Ensuite, il suffit de pointer un sondage de température et d'humidité le long d'une surface M=constante sur un téphigramme. La stabilité est par la suite évaluée de la manière habituelle. Les sondages originaux devraient être examinés en tout premier lieu pour déterminer la présence ou l'absence d'instabilité conditionnelle (évaluée de la manière habituelle). S'il y a instabilité conditionnelle, il n'est pas nécéssaire d'évaluer le potentiel pour de la convection inclinée . On voit donc que le concept d'instabilité symétrique n'est pas une panacée, mais plutôt un outil supplémentaire qui nous permettra peut-être de trouver de l'instabilité selon un plan incliné lorsqu'il n'y en pas dans le plan vertical.

Il est également possible d'utiliser un sondage pour estimer la stabilité de l'atmosphère à la convection inclinée pour les particules qui ont été échantillonées par le sondage. Une façon rapide et simple est d'ajouter à la température de la particule soulevée l'excédent de température provenant de la contribution de la force centrifuge. L'évaluation de la stabilité se fait par la suite de la façon habituelle. Le lecteur intéressé pourra consulter *Emanuel (1983b)*.

La question qui se pose dans l'évaluation opérationnelle de la stabilité symétrique est la suivante: Est-ce que la résolution de mon réseau d'observation en altitude en temps réel est suffisante pour résoudre un phénomène de mésoéchelle tel que la convection inclinée? Une revue des diverses études de cas (*Emanuel, 1983b; Sanders et Bosart, 1985; Sanders, 1986; Emanuel, 1988; Moore et Blackley, 1988; Reuter et Yau, 1990*) nous indique que la distance moyenne entre les stations de radiosondages utilisées pour évaluer la stabilité symétrique varie de 200 à 400 km. Cette distance moyenne tombe à environ 150 km lors des expériences CASP et GALE. Evidemment, plus la distance est petite meilleur sera le résultat. De plus, au-delà de 500 km, il est douteux que les resultats obtenus soient significatifs. La distance moyenne entre les stations de radiosondages américaines se situe entre 300 et 400 km ce qui est probablement acceptable (bien qu'à la limite) pour évaluer la stabilité symétrique. Dans le sud du Québec cette distance moyenne est de 550 km. Si la coupe verticale qui est nécéssaire s'étend du nord vers le sud sur le centre de la province,

cette distance passe à 650 km. A certains endroits du Canada cette distance est supérieure à 650 km. Il est donc évident dans le contexte actuel que l'évaluation de la stabilité symétrique avec un tel réseau synoptique apportera des résultats très contestables et l'apport d'information obtenu par rapport à l'évaluation traditionnelle de la stabilité sera très marginal. On peut donc oublier le diagnostic de la stabilité symétrique en temps réel, mais on pourrait certainement utiliser les variables prévues par les modèles numériques pour analyser la convection inclinée. Avec l'avènement du nouveau réseau de communication, des systèmes MPDS dans les bureaux régionaux et de la future station de travail, il sera relativement facile d'avoir des profils de température et d'humidité prévus le long de surface M=constante.

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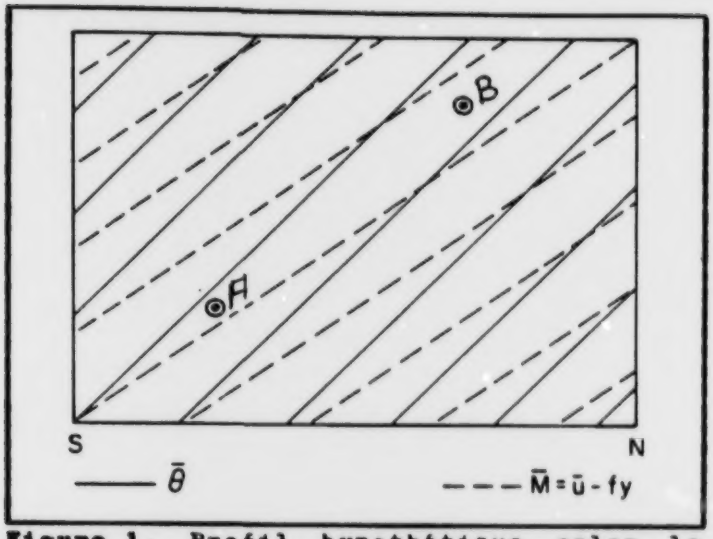

Figure 1. Profil hypothétique selon le plan y-z de O et de M sous les conditions d'instabilité symétrique (adapté de *Lilly, 1986*)

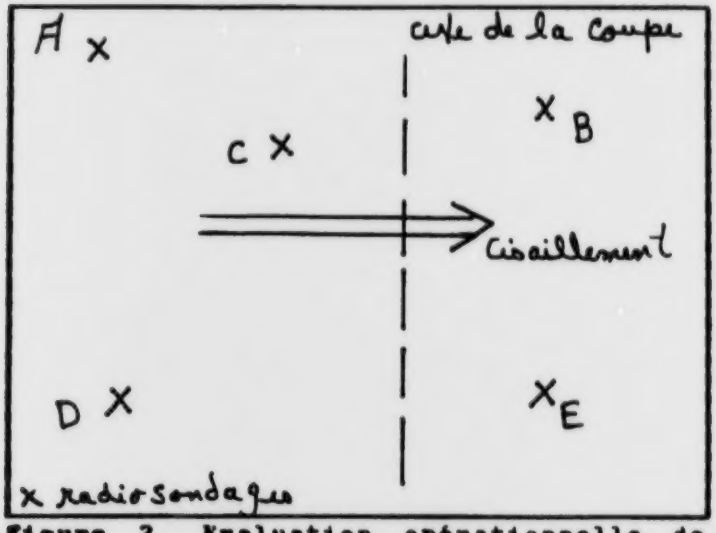

Figure 2. Evaluation opérationnelle de l'instabilité symétrique à l'aide d'un réseau de radiosondage.

THE RELATIONSHIP BETWEEN PRECIPITATION BANDS AND SLANTWISE CONVECTION IN A BAROCLINIC ATMOSPHERE

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Abstract: The stability properties of the atmosphere are investigated using observations of the Canadian Atlantic Storms Program. Seven cases with precipitation bands are analysed. The atmosphere is shown to contain shallow layers of air that are neutral or slightly unstable for conditional slantwise convection. In the upper levels, the potential for instability usually remains only a potential because the lack of moisture precludes the actual release of energy. In the lower part of the atmosphere saturation is often realized and the instability is released leading to heavy precipitation organized in bands.

Résumé: Les observations du Canadian Atlantic Storms Program sont utilisées pour examiner les propriétés de stabilité de l'atmosphère. L'analyse porte sur sept cas montrant des bandes de précipitation. L'atmosphère présente de fines couches neutres ou faiblement instables au regard de la convection oblique. Dans les hautes couches, le plus souvent l'instabilité potentielle se maintient en raison du manque d'humidité qui empêche le relâchement de l'énergie. Dans la partie inférieure de l'atmosphère la saturation en rapeur d'eau est souvent rencontrée et l'instabilité est relâchée conduisant ainsi à de fortes précipitations organisées en bandes.

INTRODUCTION

An important problem in operational weather forecasting is to predict the organization and intensity of precipitation within extratropical winter cyclones. Heavy precipitation associated with mid-latitude cyclones is often organized in banded features oriented perpendicular to the direction of the temperature gradient. The formation of precipitation bands is closely related to the stability properties of the baroclinic atmosphere. For some temperature and moisture distributions along surfaces of constant geostrophic vorticity, the "slantwise convective available potential energy" (SCAPE) can be positive which may cause a slanted circulation (Bennetts and Hoskins 1979; Emanuel 1983). Also if frontal regions have zero or small slantwise stability, concentrated upward motion is maintained because the response to frontogenetic forcing is then particularly large (Thorpe and Emanuel, 1985). The focus of this study is on the evolution of slantwise convection using observations taken during the Canadian Atlantic Storms Program (CASP). A detailed description can be found in Reuter and Yau (1990).

CONDITIONAL SLANTWISE INSTABILITY

Provided that the vorticity due to curvature of the baroclinic flow is small compared to the Coriolis parameter (f), the stability to displacements depends solely on the distribution of temperature and moisture along surfaces of constant "absolute momentum" ($\bar{M}$), defined by $\bar{M} = \bar{v}+fx$ where $\bar{v}$ is the geostrophic flow in the direction of the thermal wind and x is the distance in the direction of the temperature gradient. The slantwise displacement of saturated air will be unstable if the slopes of the $\bar{M}$-surfaces are less than those of the equivalent potential temperature ($\bar{\theta}_e$) surfaces. If the atmosphere is moist but unsaturated, the above condition for slantwise instability becomes a necessary but not sufficient condition and the state that $\bar{\theta}_e$ decreases upward along $\bar{M}$ surfaces is termed *potential* slantwise instability. *Conditional* symmetric instability can be assessed by lifting a moist air parcel along an $\bar{M}$-surface and comparing its adiabatic temperature to that of the environment. Alternatively the instability condition can be obtained by comparing the slopes of the $\bar{M}$ surfaces with those of $\bar{\theta}_e^*$, the equivalent potential temperature for a saturated atmosphere having the same potential temperature structure given by the observations. If the air is close to saturation, typical for maritime air masses, potential and conditional instabilities are almost the same.

The Halifax radar CAPPI maps were examined to identify the occurrence of precipitation bands over the Nova Scotia region. All cases in which the 1.5 km CAPPI maps revealed some banded structure were considered. Cases with flow patterns having significant curvature were eliminated as they may violate the condition of geostrophic balance. The seven cases selected were 12, 18 UTC 28 Jan; 12, 15, 18 UTC 30 Jan; 15, 18 UTC 2 Feb; 0, 3 UTC 26 Feb; 9, 12 UTC 2 Mar; 6, 9, 12 UTC 7 Mar and 0 UTC 15 Mar. To assess the occurrence of slantwise convective instability, we construct cross sections portraying $\bar{M}$-$\bar{\theta}_e^*$ fields normal to the base flow. The x-axis is perpendicular to the direction of the low level geostrophic windshear estimated from the maximum thermal gradient of the observed temperature measurements in the 90-70 kPa layer. The geostrophic velocity component $\bar{v}$ is approximated with the observed wind. Linear interpolation is used to obtain values of $\bar{M}$ and $\bar{\theta}_e^*$ on a fine grid with a uniform horizontal resolution of 100 m. Reuter and Yau (1990) argue that the resolution of the observations is sufficient for the examination of slantwise convective instability.

CASE STUDY OF 30 JANUARY 1986

The seven cases analyzed yielded consistent results. Here, the findings for 30 January are given. The results for the other cases can be found in Reuter and Yau (1990). On 29 January a developing cyclone moved off the coast of Virginia, tracking

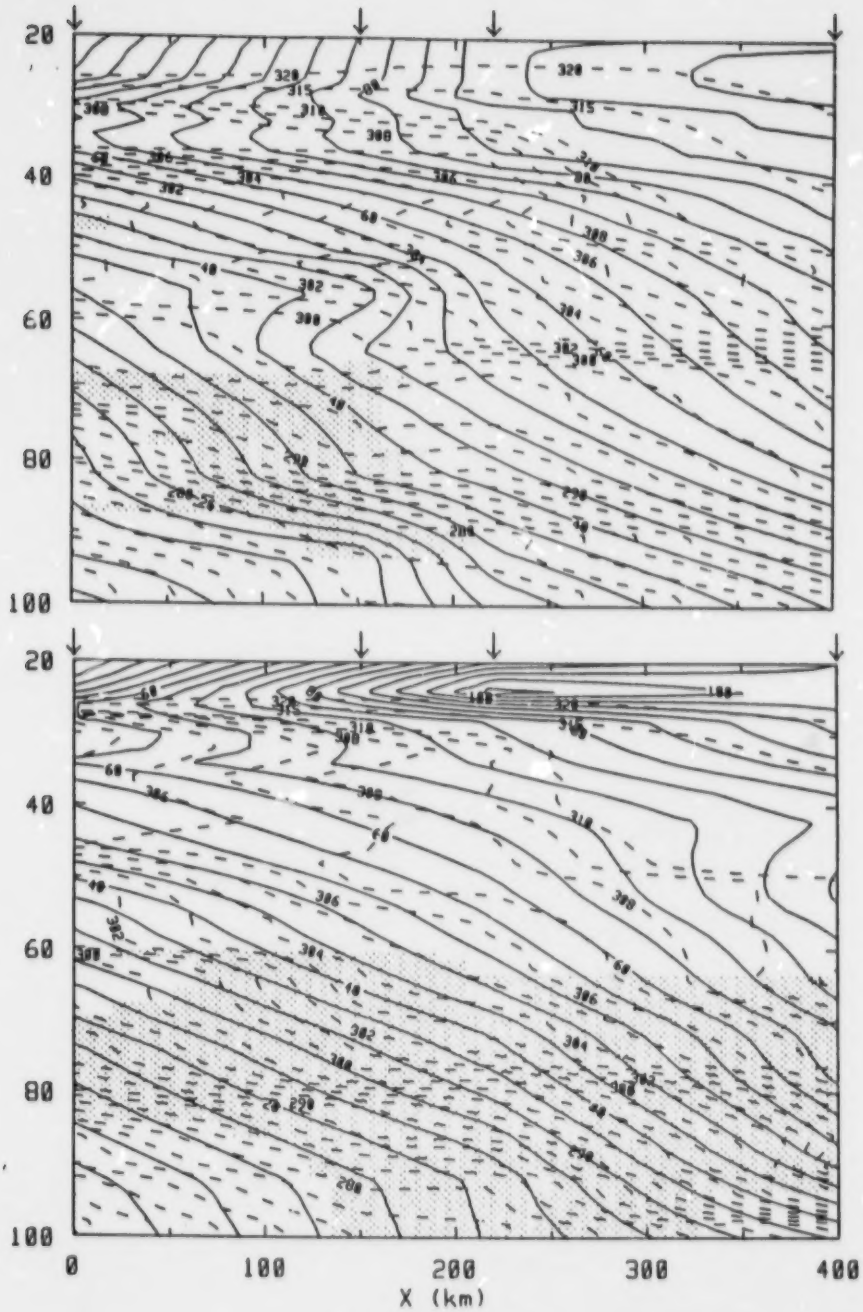

Fig.1. Vertical cross section at 1200 UTC (top) and 1800 UTC (bottom) 30 January 1986 showing absolute momentum and saturated equivalent potential temperature surfaces in solid and dashed lines respectively. The projected locations of Summerside (YSU), Shearwater (YAW), Eddy Point (WOQ) and Sable Island (WSA) are indicated by arrow. Shading denotes regions where the relative humidity is in excess of 90%.

northeastward toward Sable Island. When crossing over Newfoundland the low deepened with 1.1 kPa in 6h. 15-20 cm of snow fell along the eastern coast of Nova Scotia and over 30 cm in Newfoundland. The Halifax radar indicated two parallel precipitation bands which remained fairly stationary throughout the period 15-18 UTC on 30 January. Sounding data from four stations at 12, 15 and 18 UTC were used to construct $\bar{M}$-$\bar{\theta}_e$* cross sections normal to the observed geostrophic windshear. At 12 UTC (Fig. 1) a major portion of the atmosphere was conditionally stable with respect to slantwise convection. However, a region of conditional instability (hereafter stability and instability will refer to that of slantwise convection unless stated otherwise) can be found in the layer from 50 to 40 kPa between YSU and WOQ (0-220 km). Here strong wind shear coexisted with a temperature field which was characterized by an almost neutral lapse rate. Between WOQ and WSA (220-400 km) close to the level at 90 kPa a second region of weak conditional instability was indicated. Since the air in the unstable regions was unsaturated, the actual release of the instability was conditional on the occurrence of lifting or advection of moisture to achieve saturation.

At 15 UTC (not shown) regions of conditional instability were located from 55 to 45 kPa and at a level about 75 kPa between WOQ and WSA (220-400 km). The conditionally unstable air had relative humidity values beneath 90%. In the saturated regions, the air was either stable or close to a state of neutrality. At 18 UTC a layer of conditional instability was still present in the upper troposphere. Again the absence of a sufficient amount of moisture precluded condensation at altitudes above 60 kPa. In

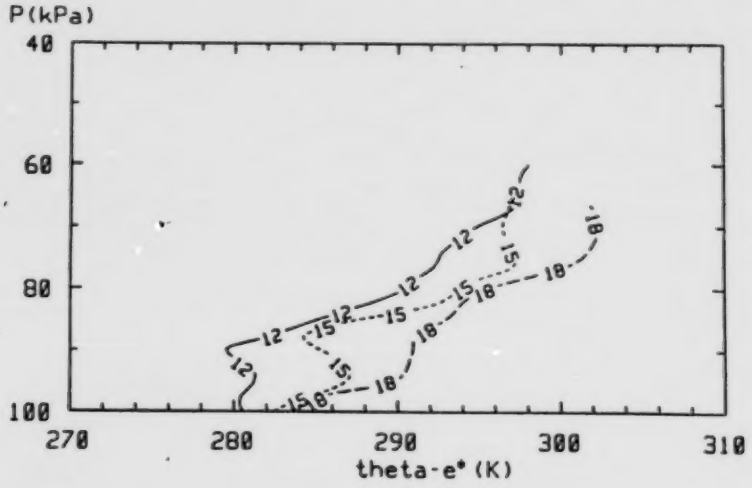

Fig. 2. The saturated equivalent potential temperature plotted against pressure along the surface of constant angular momentum $\bar{M}$ = 36 m/s at 12, 15 and 18 UTC 30 January 1986.

contrast, the air mass in the lower and middle troposphere had experienced sufficient lifting to develop a deep layer of cloudy air. Between YAW and WSA (150-400 km), the saturated air bounded by $\bar{M}$ values of 36 and 48 m/s was fairly close to a state of conditional slantwise neutrality.

Fig. 2 displays the evolution of $\bar{\theta}_e$* along the $\bar{M}$=36 m/s surface. At 12 UTC, the air between the 95 and 90 kPa layer exhibited conditional instability. At 15 UTC the instability weakened only slightly, while the air was still unsaturated. Condensation took place between 15 and 18 UTC and it is noted that within these three hours, conditional instability has vanished along this particular $\bar{M}$ surface.

CONCLUSION

All cases considered had in common that the major portion of the domain depicted in the vertical cross sections was stable to slantwise convection, with some saturated regions where the air was close to a state of slantwise neutrality. Small portions of the analyzed cross sections, however, seemed to indicate the presence of conditional slantwise instability. Typically these regions were sloped layers consisting of unsaturated air in a regime of strong vertical shear. It is conceivable that slantwise convection may have occurred more often during the three month period. But even so, seven events of slantwise neutrality or weak symmetric instability offers sufficient support to suggest that slantwise convection is not a rare phenomenon but is likely to be ubiquitous at least for active baroclinic zones such as Atlantic Canada during the winter months. The occurrence of slantwise convection during CASP was also reported by Donaldson and Stewart (1989).

The evolution of regions that exhibited conditional instability was examined. One area of instability was found in upper atmospheric layers that contained unsaturated air and pronounced vertical shear. In most cases the instability was not released because of a lack of sufficient moisture. The situation was quite different at lower levels where moisture was available in many cases to allow the air to reach saturation. The moisture source usually resulted from advection by an easterly flow which carries humid maritime air over Nova Scotia. Lifting of the boundary layer air also contributed to the formation of clouds which may result in the release of slantwise instability. The timing and location of the release of the energy was correlated with the formation of bands with heavy precipitation. Although it appears likely that the formation of the multiple bands may be related to slantwise convection, the available observations were inadequate to allow a clear distinction between slantwise convection and the response of the atmosphere to baroclinic and frontogenetic forcings. The latter has been shown to play a major role in the formation of some precipitation bands.

Once the air became saturated, the atmosphere tended toward a state of conditional slantwise neutrality and the adjustment occurred within only three hours, consistent with observations by Emanuel (1983). If convincing evidence could be found that this is indeed always the case, then the parameterization of slantwise convection in numerical weather prediction models would in principle be rather straightforward. The heat and moisture fields would have to be adjusted to its neutral state along saturated $\bar{M}$ surfaces.

As winter precipitation and symmetric stability are closely related, it may be useful to compute the slantwise stability properties on an operational basis for selected cross sections in baroclinic active regions such as Atlantic Canada. Quantitative information about slantwise stability may provide an additional aid in determining the likelihood of heavy precipitation.

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APPLICATIONS OF FUTURE GOES MULTISPECTRAL IMAGERY

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Abstract

The GOES-I satellite, scheduled to be launched by early-1992, will have a total of 5 image channels. Two infrared (IR) channels, at 3.9μm and 12.0 μm, have been added to supplement the visible, 11 μm IR and 6.7μm water vapor images currently available. The resolution of all infrared channels, including water vapor, will improve by factor of 2. Applications of the GOES-I imagery are described, with an emphasis on the new IR channels.

Le satellite GOES-I qui sera lancé au début de 1992 disposera de 5 canaux. Deux canaux infrarouges(IR), 3,9îm et 12,0îm complémenteront les canaux déjà disponibles i.e. visible, 11îm IR et 6,7îm (absorption par la vapeur d'eau). La résolution de tous les canaux infrarouges, y compris le canal d'absorption de la vapeur d'eau, sera doublé. Nous décrirons les applications de l'imagerie de GOES-I en mettant l'emphase sur les nouveaux canaux IR.

INTRODUCTION

The GOES-I, the first in a new series of advanced geostationary meteorological satellites, is due to be launched by the U.S. by early 1992. The satellite will have a revolutionary design that will feature: independent imager and sounder systems, three-axis stabilization instead of the current spin stabilized spacecraft, independent WEFAX and an improved imaging system. The change that will have the most noticeable effect on the largest number of users is the advanced imaging system. A total of 5 channels of image data will be produced every 30 minutes, an increase from the 3 currently available. A summary of these channels is shown in Table 1.

Two new infrared (IR) channels have been added, a short-wave (3.9 μm) and long-wave (12.0 μm) window channel. These will supplement the 10.7 μm IR window and 6.7 μm water vapor (WV) absorption band, which are similar to those on the current GOES. The IR channels will have improved spatial resolution by a factor of 2, to 4 km at the satellite subpoint, except 8 km for WV imagery. These resolutions will degrade to about 7 km and 14 km, respectively, at the latitude of Montreal. The improved resolution of IR imagery will allow better definition of small scale phenomena such as: overshooting thunderstorm tops, small convective cells, wave clouds, and topographic features. The visible (VIS) channel from GOES-I will have a 1 km resolution, the same as GOES-7, but 10-bit quantization will allow the display of four times the number of gray shades now possible. The new IR channels planned for the "GOES-Next" series are currently available from GOES-7, but only in the sounding or MultiSpectral Imaging (MSI) modes, at lower resolution and infrequent intervals (ranging from 11/2 to 8 hours). Despite these deficiencies, their availability provides an opportunity to preview their capabilities in various meteorological applications, both alone and in tandem with existing channels. This paper will briefly describe potential applications of the GOES-I imager.

Table 1.
GOES I-M Imager Channels

Channel #	Wavelength (μ)	Type	Resolution (km)	Used for
1	.55-.75	VIS	1	Cloud imaging Snow and Ice Topography
2*	3.9	IR	4	Fog/stratus Clouds vs snow Fires
3	6.7	WV	8	Upper flow Jet streaks Convection
4	10.7	IR	4	Cloud imaging Cloud tops
5*	12.0	IR	4	Cloud imaging SST, moisture

* New channels

IMAGE APPLICATIONS

Synoptic Scale Analysis

Two GOES-I channels now available with GOES-7 (IR and WV) will continue to be valuable tools in analysis of synoptic scale features important in weather forecasting. WV in particular seems to be adept at detecting upper level features such as troughs, vorticity maxima and jets that are difficult to observe in IR. The improved resolution should eliminate some of the graininess now observed in WV images. A composite of the two image types has been suggested as a future product from GOES-I. This combined image format can more efficiently utilize the information available from both channels.

Severe Thunderstorm Detection

The combination of WV and 10.7μm IR will also play an important role in severe thunderstorm analysis. In addition to the identification of upper level "trigger" mechanisms, the locations of upper dry zones which may enhance potential instability can be monitored. Differences in the two longwave IR windows (Channels 4 & 5) can be used to show the spread of low level moisture. Once convection develops, the detection of severe thunderstorm signatures such as the "Enhanced-V", cold-warm couplets, and WV darkening on the upstream anvil edge will be made easier because of improved spatial resolution in both channels.

Nighttime Fog/Stratus Detection

One of the most versatile IR channels will be the short wavelength (3.9 μm - Channel 2) window. It is analagous to Channel 3 from the NOAA Advanced Very High Resolution Radiometer (AVHRR) instrument. It contains a wealth of information, but the tradeoff is that it is often more difficult to interpret. One of its most important capabilities is the nighttime detection of stratiform clouds, including fog. Fog and stratus often have cloud top temperatures very similar to surrounding clear zones, making detection difficult with IR imagery. The lower emissivity of stratus clouds in Channel 2 will result in a slightly lower temperature than in Channel 4 IR images. This is because fog forms beneath a pronounced inversion, with colder temperatures near the surface.

While the Channel 2 images alone will result in improvement in fog detection, the difference between the two channels has been shown to be preferable (Eyre, et al., 1984; Ellrod, et al., 1989). The technique works equally well over land or water. Figure 1 shows an example of this capability over the western United States on 21 February, 1990. In addition, the digital brightness difference of the two channels appears to be correlated with fog thickness, which is vital information to determine the forecast time of clearing. The technique cannot distinguish between stratiform clouds at different levels, so the imagery must be supplemented by surface observations.

Delineating Clouds from Snow Cover

During daylight hours, strong backscattering of sunlight off liquid water clouds at 3.9 μm (Channel 2) makes the clouds appear relatively warm (dark); whereas ice clouds and snow cover are less reflective at this wavelength (Kidder and Wu, 1984). This characteristic permits differentiation of low clouds from snow or ice, a difficult problem at high latitudes, especially without image animation. Figure 2 is an example of how a combination of Channels 1 and 2 can discriminate snow cover from clouds which have liquid water droplets (dark areas). This capability may also be useful in forecasting areas of aircraft icing.

Fire Detection

The 3.9 μm IR sensor (Channel 2) is more responsive to intense heat sources such as forest fires than the 11 μm channel. In the past, this capability has only been possible with high resolution AVHRR imagery (Matson, et al., 1984). However, low solution (4 km) AVHRR Global Area Coverage (GAC) images have also been used for this purpose, providing some promise for GOES-I Channel 2. The detection of fires still requires considerable image enhancement, and is best done at night when temperature contrasts are greatest.

Thin Cirrus Detection

WV imagery is often helpful in defining regions where thin cirrus may be present. Cirrus is not a major forecast problem, but its presence inhibits radiational cooling and thus affects predictions of minimum temperatures and fog formation. More positive identification can be obtained from a differencing of Channels 2 and 4 (described previously) or 4 and 5. In a Channel 2-4 comparison, for example, thin cirrus appears warmer in Channel 2. This difference is due to the combination of lower emissivity in Channel 2 and the presence of warmer air beneath the cirrus.

CONCLUSION

It can be seen that the GOES-I imager will provide the capability of many more applications than are currently possible. However, many of the uses just described require direct ingest and digital display and analysis systems. Users on the U.S. GOES-Tap facsimile network and direct broadcast WEFAX will see few changes from the type of images currently received (VIS, IR, WV). Nevertheless, the more widespread use of this new data appears to be just around the corner.

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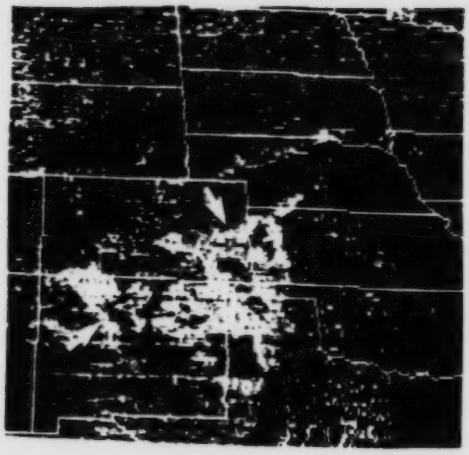

Figure 1. Image created from difference of GOES-7 3.7μm and 11μm infrared channels at 0921 UTC, 21 February 1990. Fog and stratus are located in bright areas. Black or mottled white shows regions of cirrus.

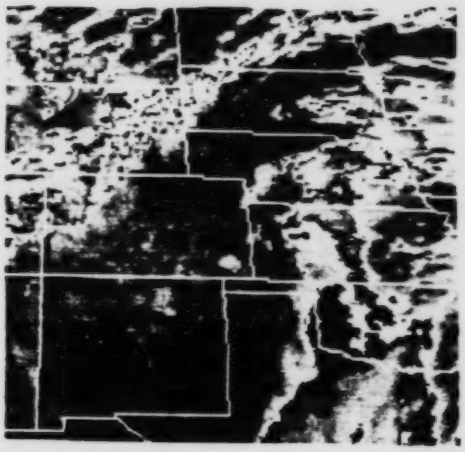

Figure 2. GOES-7 11μm channel image at the same time as Figure 1.

Figure 3. GOES-7 3.7μm IR image at 1830 UTC, 21 February 1990. Strong backscattering of sunlight by liquid water clouds helps separate them from snow cover.

Figure 4. GOES-7 visible image at 1830 UTC, 21 February 1990.

Evaluation de la fonction de déformation dans le calcul du mouvement vertical.

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RESUME. *Une révision de la méthode d'évaluation d'oméga telle qu'employée au centre météorologique du Québec est présentée. Une analyse d'échelle sera faite et les suppositions inhérentes à la méthode seront discutées. Une comparaison des différents termes pour un cas de CASP sera présentée. Nous montrerons que pour ce cas la fonction de déformation peut-être négligée à l'échelle synoptique.*

ABSTRACT. *A review of the technique used by the Quebec weather centre to evaluate omega is presented. A scale analysis of the various terms and the approximations made to derive the technique is shown. The magnitude of some of the terms is computed for a case of explosive cyclogenesis during CASP. It will be shown that for synoptic scale the deformation function can be neglected for that particular case.*

1. INTRODUCTION.

Le mouvement vertical dans l'atmosphère, dérivé à partir de diverses formes de l'équation oméga, est l'un des champs de base avec lequel les prévisionnistes travaillent en temps réel. L'équation d'oméga quasi-géostrophique s'est montré particulièrement utile étant donné qu'elle permet d'expliquer plusieurs règles de la météorologie synoptique, règles qui sont basées sur les principes dynamiques de l'atmosphère.

Il y a plusieurs manières d'obtenir une solution pour oméga. On pourrait résoudre l'équation de balance qui tient compte des termes ageostrophiques *(Krishnamurti, 1968a,b)*. La difficulté de un tel système est qu'il est à peu près impossible de résoudre le problème en temps réel, l'ellipticité des équations différentielles étant difficile à maintenir en présence de forçage diabatique ce qui pose un problème pour la stabilité du schème numérique. Une autre aproche consiste à approximer les termes de forçage dans l'équation d'oméga quasi-géostrophique de telle sorte que l'on puisse obtenir une évaluation rapide et qualitativement correcte du mouvement vertical. Cette approche a été choisie par le monde opérationnel car elle est simple d'application et donne une estimation rapide d'oméga dans le plan horizontal, en supposant un profil vertical périodique. Cette approche, à cause des suppositions que l'on doit faire, s'applique généralement à la moyenne troposphère. Lorsqu'on tente d'appliquer ces suppositions à la basse ou à la haute troposphère, il faut évaluer la dimension des termes que lon négligeaient précédemment.

2. APPROCHE DE TRIBBIA (1978).

L'équation d'oméga quasi-géostrophique est obtenue en éliminant les dérivées locales par rapport au temps entre l'équation de tourbillon géostrophique et l'équation thermodynamique tout en négligeant le réchauffement diabatique ainsi que la friction (équation 1).

$$\frac{\partial \zeta}{\partial t} = -\mathbf{V}\cdot\nabla_\psi + \omega\frac{\partial \omega}{\partial p}$$

$$\frac{\partial}{\partial t}\frac{\partial \phi}{\partial p} = -\mathbf{V}\cdot\nabla\frac{\partial \phi}{\partial p} - \sigma(p)\omega$$

$$(F_1) \qquad (F_2)$$

$$\left(\nabla^2 + \frac{f_0^2}{\sigma}\frac{\partial^2}{\partial p^2}\right)\omega = -\frac{f_0}{\sigma}\frac{\partial}{\partial p}(\mathbf{V}\cdot\nabla_\psi) - \frac{1}{\sigma}\nabla^2\left(\mathbf{V}\cdot\nabla\frac{\partial \phi}{\partial p}\right) \qquad (1)$$

L'interprétation de cette équation se fait comme suit. Le côté gauche (CG) est un laplacien tri-dimensionnel

approximé par (-1.0*oméga). Ceci est permis si on suppose un profil périodique (sinusoidal par exemple) pour oméga dans la verticale(figure 1). Le côté droit (CD) est une fonction de forçage qui contient deux composantes: F_1 est la dérivée verticale de l'advection absolue de tourbillon et F_2 est le laplacien de l'advection thermique.

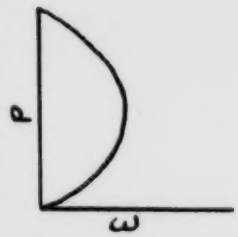

Figure 1. Profil de w(p).

Un des problèmes avec cette formulation est que F_1 et F_2 ne sont pas mutuellement indépendants. La supposition que F_1 représente l'advection de tourbillon à 500 mb sans considéré la contribution des bas niveaux constitue une inéxactitude. De la même façon, de considérer que F_1 renforce toujours F_2 constitue également une erreur. Pour pallier à ce problème, Trenberth (à partir d'ici T78) réécrit le CD de l'équation oméga (équation 2)

$$\left.\begin{aligned} F1 &= J\left(\frac{\partial\psi}{\partial p},\nabla\psi\right)+J\left(\frac{\partial\psi}{\partial p},f\right)+J\left(\psi,\frac{\partial}{\partial p}\nabla\psi\right)\\ &\quad A \quad + \quad C \quad + \quad B \end{aligned}\right\},$$

$$F2 = -J\left(\nabla\psi,\frac{\partial\psi}{\partial p}\right)-J\left(\psi,\nabla^2\frac{\partial\psi}{\partial p}\right)$$

$$A \quad - \quad B$$

$$-2\left[J\left(\frac{\partial\psi}{\partial x},\frac{\partial^2\psi}{\partial x\partial p}\right)+J\left(\frac{\partial\psi}{\partial y},\frac{\partial^2\psi}{\partial y\partial p}\right)\right]$$

$$- \qquad 2\Lambda\left(\psi,\frac{\partial\psi}{\partial p}\right) \qquad (2)$$

La fonction de déformation, que nous appellerons gamma, dans l'équation (2) est du type

$$\Lambda\left(\psi,\frac{\partial\psi}{\partial p}\right)=J\left(u,\frac{\partial u}{\partial p}\right)+J\left(v,\frac{\partial v}{\partial p}\right)$$

$$=\frac{R}{pf}\left[J\left(u,\frac{\partial T}{\partial y}\right)-J\left(v,\frac{\partial T}{\partial x}\right)\right]$$

$$=\frac{1}{2}\left[E\frac{\partial D}{\partial p}-D\frac{\partial E}{\partial p}\right]$$

$$D=(\partial v/\partial x)+(\partial u/\partial y),$$
$$E=(\partial u/\partial x)-(\partial v/\partial y)$$

La technique utilisée au centre météorologique du Québec (CMQ) consiste essentiellement à utiliser l'advection de tourbillon absolue par le vent thermique qui approxime la somme de F_1 et de F_2. Les suppositions à faire sont discutées dans la section 3. Cette approche est simple et peut-être appliquer aux opérations météorologiques en temps réel. A partir de ce champ, on peut établir des corrélations entre les accumulations de précipitations et l'eau précipitable sur des cas historiques de telle sorte que lon utilise ces régressions dans un mode prévisionnel.

3.ANALYSE D'ECHELLE. SUPPOSITIONS.

Pour en arriver à l'équation (9b) de T78 on doit négliger gamma. Historiquement, on a considéré que cette supposition était valide dans la moyenne troposphère (entre 400 et 600 mb). Ailleurs, la baroclinicité est plus importante et cette supposition est moins acceptable car les cisaillements horizontaux et verticaux du vent y sont plus importants. La seconde supposition est que le CG de l'équation d'oméga puisse être interpréter comme (-1*oméga). Encore une fois le domaine de validité de cette supposition se situe entre 400 et 600 mb *(Miin-Nielsen, 1959; Trenberth, 1978)*.

Il y a très peu d'études, à notre connaissance, qui adresse spécifiquement le problème de l'évaluation de la fonction gamma. Tout le monde s'accorde pour dire que ce terme est petit dans toute la

troposphère à l'échelle synoptique. On tire cette conclusion sur la base des estimations d'oméga à partir de différentes méthodes. Par exemple, la méthode du vecteur Q *(Hoskins et Pedder, 1980)* contient tout les termes de manière implicite alors que T78 suppose que gamma est négligeable. *Dunn (1988)* a montré que les champs de mouvement vertical obtenu à partir de ces deux méthodes, entre autres, n'étaient pas très différents. D'où la conclusion que les autres termes comme la fonction de déformation ne sont pas très importants.

Une analyse d'échelle nous indique que la variation selon p de l'advection de tourbillon absolue par le vent thermique est $O(10^{-11}\ mb^{-1}\ s^{-2})$ et la fonction gamma est $O(10^{-12}\ mb^{-1}\ s^{-2})$. A l'échelle synoptique la fonction gamma est donc négligeable. Localement elle se comparera à l'advection de tourbillon absolue par le vent thermique là ou la déformation horizontale et/ou sa variation verticale seront d'un ordre de grandeur supérieur. Cette éventualité peut se produire à proximité des courants-jet de bas et de haut niveaux. On doit donc avoir une résolution horizontale et verticale suffisante pour analyser correctement ces phénomènes ce qui n'est pas le cas avec les réseaux actuels d'observation. Par contre dans un futur rapproché, les modèles numériques auront cette capacité et la fonction gamma devra être considérée. L'emploie direct du mouvement vertical du modèle devra également être considéré car aux échelles plus petites, les suppositions sous-jacentes à la théorie quasi-géostrophique ne tiennent plus et le système d'équation complet doit être résout pour obtenir oméga.

4.RESULTATS DES CALCULS: CAS 14 DE CASP.

Pour avoir une idée quantitative de la grandeur de gamma par rapport aux autres termes, un épisode de cyclogénèse explosive le long de la Côte Est a été choisi. Le cas 14 de l'expérience CASP *(Stewart et al., 1987)* a été sélectionné car de nombreux auteurs s'y sont intéressé, entre autres *Mailhot et al., 1989* pour la performance des modèles numériques et *Yau et Jean, 1989*, pour la situation synoptique de cet épisode. La phase de développement rapide de ce système s'étend du 7 mars 1986 à 00 TU au 7 mars 1986 12 TU (figure 3). Les calculs ont été exécutés à 00, 06, 12 et 18 TU, mais seul le cas au temps 12 TU est montré puisque les résultats sont assez semblables pour les autres temps.

Tous les termes dynamiques ont été calculés sur le domaine indiqué à la figure 2. Les figures 4a et 4b montrent les champs de géopotentiels à 500 mb ainsi qu'à 1000 mb. *Yau et Jean (1989)* ont montré que les mécanismes frontogénétiques étaient importants tout au long de la cyclogénèse dans les bas niveaux ainsi qu'au niveau du courant-jet. La présence d'un courant-jet de bas niveau a également été mise en évidence. La figure 5a montre le champ d'advection de tourbillon par le vent ainsi que par le vent thermique (figure 5b) à 500 mb. Il est évident que les deux champs se comparent bien sauf là où les advections thermiques sont importantes. La figure 6a montre la variation verticale de l'advection de tourbillon par le vent thermique (qui approxime le côté droit de l'équation oméga) à 500 mb et la figure 6b montre la fonction de déformation au même niveau. On constate que la fonction de déformation est d'un ordre de grandeur inférieure à l'advection de tourbillon par le vent thermique. Pour ce cas de cyclogénèse, la même conclusion peut-être tirée à 850 ainsi qu'à 700 mb (non-montrés). On en conclut donc que la supposition qui est valide. On se doit de pointer que les calculs ont été faits sur une grille dont l'espacement des points dans l'horizontale est de 381 km et n'utilisent que les niveaux

obligatoires dans la verticale. La résolution grossière ne résout probablement pas les échelles plus fines et l'intensité de phénomènes à une échelle plus petite comme les courants-jet de bas niveaux par exemple.

L'effet de la résolution dans le calcul de la fonction de déformation a été étudié *(Jean, 1990)*. Le calcul de la fonction de déformation avec des données non-lissées (résolution: horizontale 200 km, verticale 30 mb) donne un ordre de grandeur $O(10^{-11})$. La possibilité est donc réelle que la fonction de déformation puisse être localement comparable à l'advection de tourbillon par le vent thermique (si la grandeur de ce terme ne change pas, ce qui n'est pas évident aux échelles plus petites; voir *Patoine et Verret (1990)*) si l'on possède une résolution suffisante pour bien résoudre les forts cisaillements du vent associés à des phénomènes de méso-échelle.

5.CONCLUSION.

Une revue de la méthode d'évaluation du mouvement vertical telle que décrite dans *I78* et telle qu'employée au centre météorologique du Québec a été faite. Une analyse d'échelle ainsi que les suppositions inhérentes à la méthode ont été présentées. Il a été montré que pour un fort cas de cyclogénèse, en l'occurence le cas 14 de CASP, la fonction de déformation à tous les niveaux était d'un ordre de grandeur inférieur au forçage de l'équation oméga ce qui est en accord avec *I78*. En utilisant des données brutes de stations aérologiques, dont la résolution verticale était d'environ 3 à 5 fois supérieure au premier ensemble de données, nous avons trouvé que la fonction de déformation était d'un ordre de grandeur comparable à la grandeur typique de la variation verticale de l'advection de tourbillon par le vent thermique à l'échelle synoptique.

La méthode actuellement en opération au centre météorologique du Québec est donc valide en autant qu'elle soit appliquée sur des échelles pour lesquelles la théorie quasi-géostrophique (telle qu'employée) s'applique. Les raisons historiques de l'emploie de cette méthode pour diagnostiquer et prévoir oméga devraient être réévaluées à la lumière des améliorations récentes aux modèles de prévision numérique dont la résolution en (x,y,p) ne cesse de s'améliorer et dont les nouveaux schèmes d'initialisation permettent d'avoir un champ d'oméga réaliste au temps initial. A ce sujet, les résultats présentés par *Patoine et Verret (1990)* devraient être analysés avec intérêt.

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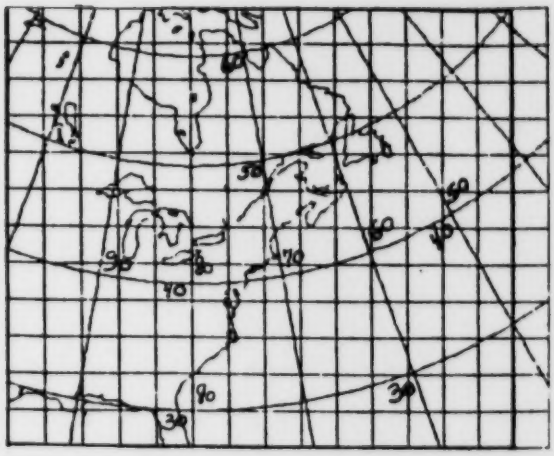

Figure 2. Domaine utilisé dans le calcul des termes dynamiques. Projection stéréographique polaire. Intervalle de grille 381 km à 60°N.

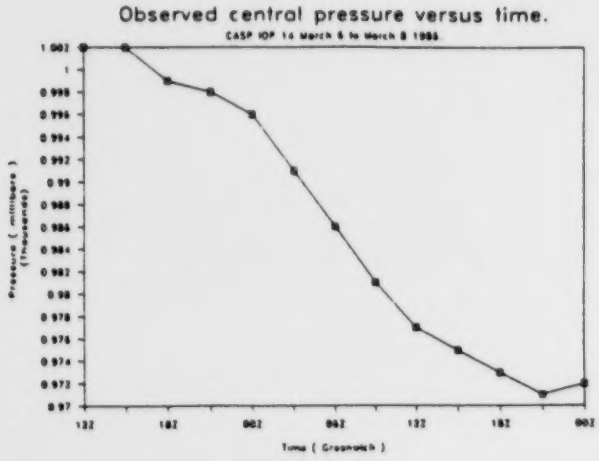

Figure 3. Evolution de la pression centrale du 6 au 8 mars 1986.

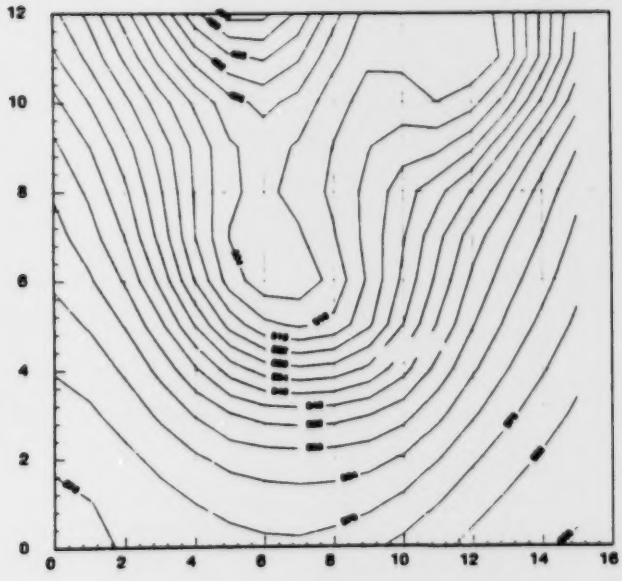

Figure 4a. Géopotentiel au niveau p=500 mb (dam) 7/12/86 12 TU.

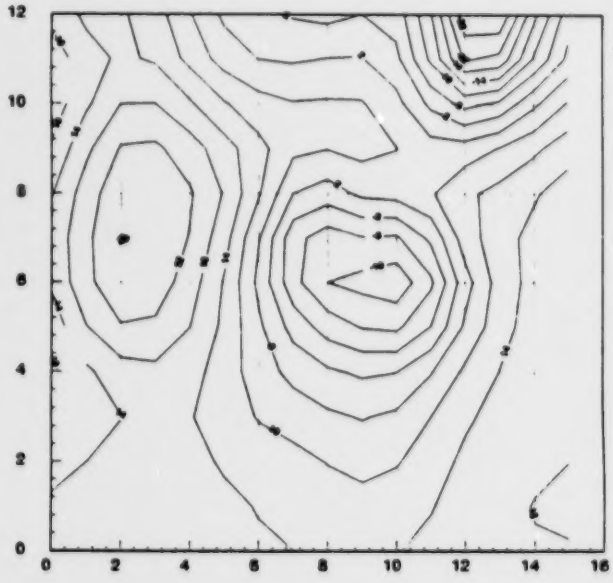

Figure 4b. Géopotentiel au niveau p=1000 mb (dam). La date est la même qu'en 4a.

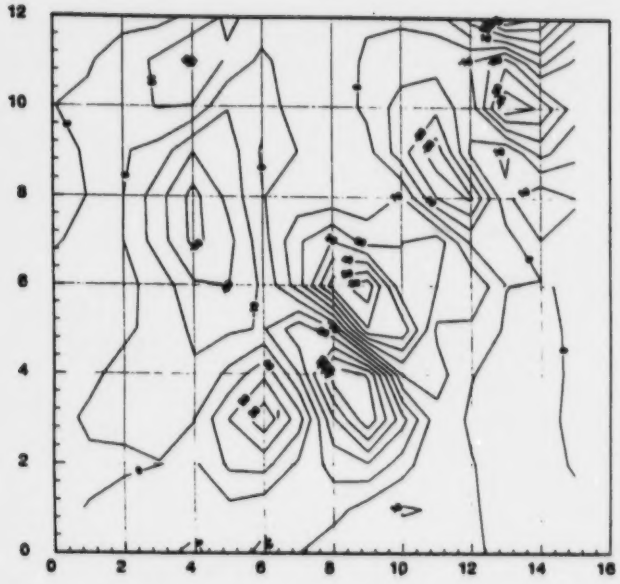

Figure 5a. Advection de tourbillon absolu par le vent à p=500 mb (10^{-10} s^{-2}).

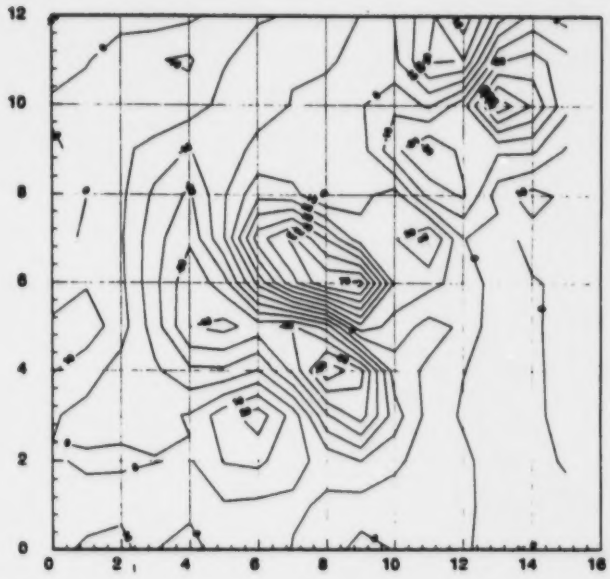

Figure 5b. Advection de tourbillon absolu par le vent thermique à p=500 mb (10^{-10} s^{-2}).

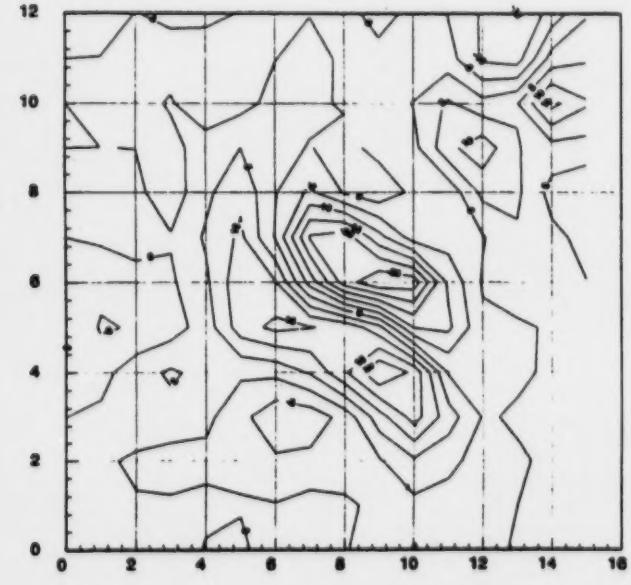

Figure 6a. Variation verticale de l'advection de tourbillon absolu par le vent thermique à p=500 mb (10^{-12} mb^{-1} s^{-2}). Ce terme approxime $F_1 + F_2$ dans l'équation (2).

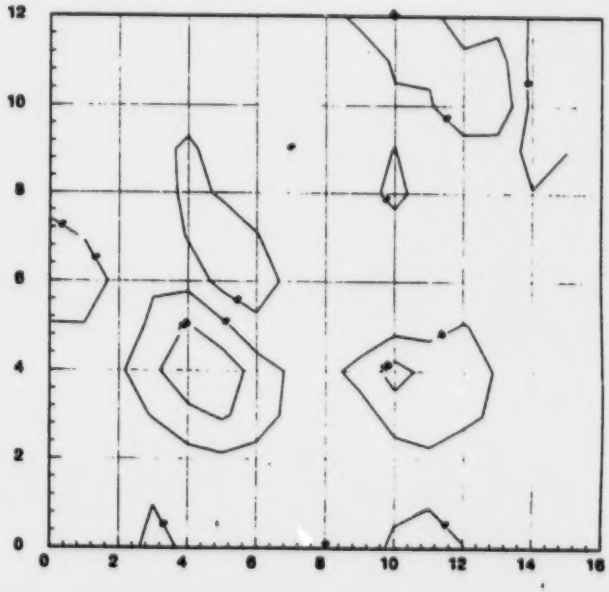

Figure 6b. Fonction de déformation gamma à p=500 mb (10^{-11} mb^{-1} s^{-2}). Voir l'équation (2) pour plus de détails sur les composantes de ce terme.

USING SEA LEVEL GEOSTROPHIC VORTICITY FOR IDENTIFYING AND FOLLOWING THE EVOLUTION OF SURFACE SYSTEMS

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ABSTRACT

Surface weather maps have hardly changed since the period between the World Wars in spite of the many advances in theory and technology. The theoretical and computer technology developments have influenced the upper air maps that are used operationally in North America. After some theoretical and practical considerations, the author suggests that sea level geostrophic vorticity should useful for following surface weather systems and associated vertical motion fields. A few cases will be presented during the poster session.

RÉSUMÉ

Les cartes de surface ont très peu changé depuis le période entre des guerres mondiales malgré plusieurs avances théoriques et technologiques. Le développement de la théorie et la technologie informatique a influencé les cartes en altitude utilisés en exploitation en Amérique du Nord. Après des discussions de nature théorique et pratique, l'auteur suggère que le tourbillon géostrophique au niveau de la mer devrait être utile a fin de suivre des systèmes en surface et les champs de mouvement vertical associés. Quelques cas seront présentés à la session d'affichage.

1. SURFACE MAPS THROUGH THE LAST CENTURY

The surface weather map has been one of the basic tools of operational meteorology for over a hundred years. Until the end of World War I, isobars and isotherms or variants of these two fields, were the standard lines drawn on the map which usually included station plots. Weather forecasters followed weather systems which were identified as low and high pressure centers as well as troughs and ridges. Although there was a good correlation between surface pressure systems and weather, it was not perfect. During and in the years following World War I, the famous Norwegian frontal model was developed that improved the situation considerably. Now weather could be identified with surface features as well as upper air extensions of these systems. Frontal analysis, however, was considered to be as much an art as a science. In North America, there was much resistance to fronts and it took almost twenty years before they became routine North American weather maps. It is still generally agreed that meteorologists require a number of years of experience to become expert frontal analysts. Every student of meteorology remembers his first set of analyses, which were generally canned "classical" cases, and the difficulty in finding exactly the same fronts that the instructor had no trouble finding. The real crunch occurs when confronted with ordinary weather situations where fronts develop, decay and often do not behave according to the rules. Efforts to produce automated objective frontal analysis have never succeeded. For a good history and recent developments in frontal analyses, the readers are referred to of Keyser (1990) elsewhere in these preprints. Todays surface weather maps still contain fronts that must be added by hand to often computer analyzed sea level pressure fields. In fact the operational surface weather map has not evolved much since the period between the World Wars and, with the exception of fronts, looks very much like the maps of over 100 years ago (see Kutzbach, 1979).

2. UPPER AIR MAPS

The upper air maps have not suffered quite the same fate since routine operational analyses became available much latter. At first pressure fields were analyzed on constant height surfaces. However, the advantages of using pressure coordinates led to the changeover in the the post World War II period to geopotential heights on constant pressure surfaces. On these maps, weather systems or waves are identified using lows, highs, troughs and ridges. With isotherms added, and the fact that the wind at upper levels is nearly geostrophic, areas of temperature advection are easily recognized from the height and isotherm analyses. With the advent of computer drawn maps and as a result of the theoretical advances in the 40's and 50's, vorticity lines were added to the 500 mb maps.

In fact the 850, 700, and 500 mb maps used in Canada today correspond essentially to the fields required to evaluate "surface development" from the Petterssen-Sutcliffe (Petterssen, 1957, p.323) development equation:

$$\left(\frac{\partial \zeta_g}{\partial t}\right)_s \equiv \left(\frac{1}{\rho_s f_o} \nabla^2 \frac{\partial p_s}{\partial t}\right) = \frac{R}{f_o} \nabla^2 \int_{p_{nd}}^{p_s} \left[\underbrace{\left(-\vec{V} \cdot \vec{\nabla} T\right)}_{A} + \underbrace{S\omega}_{B} + \underbrace{\frac{1}{c_p}\frac{dq}{dt}}_{C} \right] \frac{dp}{p} + \underbrace{\frac{1}{f_o}\left[-\vec{V} \cdot \vec{\nabla}(\zeta_g + f)\right]_{p_{nd}}}_{D} \qquad (1)$$

The "surface development" term on the left hand side, the local geostrophic vorticity tendency, represents, as indicated, the laplacian of surface pressure tendency which is positive in pressure fall maxima. The first term on the RHS of (1) is the laplacian of the integral between the surface and the level of non-divergence (p_{nd}) of the factors that contribute to temperature change in the layer: horizontal temperature advection (A), a combination of vertical temperature advection and adiabatic expansion (B), and sources (diabatic) of sensible heat such as latent heat release or heat fluxes from the ground. The second term on the right hand side is the absolute geostrophic vorticity advection by the geostrophic wind at the level of non-divergence (p_{nd}). Variations of most of these same terms are also involved in the diagnostic of vertical motion when using the the quasi-geostrophic omega equation. From current 850 and 700 mb maps we can often get an idea of the laplacian of the temperature advection between the surface and the level of non-divergence; while at 500 mb, an estimate can be made of the vorticity advection near the level of non-divergence taken to be on the average near 600 mb. The only missing terms are the vertical motion and diabatic heating terms.

The redesigned upper air maps have become essential tools for the North American meteorologist. There has been some recent debate on how to combine and display these fields (Durran and Snellman, 1987) but there seems to be a consensus that upper air maps should contain some variation of these fields. It might be pointed out that some European countries do not normally provide vorticity on the 500 mb maps which results in less use of quasi-geostrophic theory (and its derivatives) and more reliance on upper level frontal analysis, a practice generally discarded here.

3. FOR A REDESIGNED SURFACE MAP

The evolution of the upper air maps since World War II contrasts strongly with the conservative nature of surface maps. The development of quasi-geostrophic theory and its variations (semi-geostrophic, balance theory, normal mode initialization) have produced a huge gap between, on one hand, the theory and computer power available and, and on the other hand, the surface weather maps in general use today.

For example, Zwack and Okossi's (1986) development equation have shown that the atmosphere reponds on the synoptic and meso-alpha scale by the geostrophic vorticity tendency at the surface ($1/\rho f_o\ \nabla^2 \partial p_s/\partial t$), the same term as is on the LHS of (1), to factors which produce horizontal divergence. In addition, Zwack and Kabil (1988) and Zwack and Nobert (1987) have shown that surface geostrophic vorticity ($1/\rho f_o\ \nabla^2 p_{sl}$) and its tendency ($1/\rho f_o\ \nabla^2 \partial p_s/\partial t$) are quantitatively related to vertical motion in the lower half of the troposphere. These theoretical results as well as some operational experience (Bachand et. al., 1989) with numerical model initialized and forecast values of laplacian of 1000 mb geopotential height field, which is nearly identical to $1/\rho f_o\ \nabla^2 p_{sl}$, in

the forecasting of heavy winter precipitation as well as summer severe weather suggest routine analysis of $(\zeta g)_{sl} = 1/\rho f_o \nabla^2 p_{sl}$ should be useful for operational meteorology.

It might be pointed out that from the beginning of surface maps meteorologists have been implicitly identifying regions of positive or negative geostrophic vorticity ($1/\rho f_o \nabla^2 p_{sl}$) on surface maps as well as have been trying to estimate their importance. Lows and troughs are minima in the pressure field and correspond to positive geostrophic vorticity while ridges and highs are the opposite. Usually the central pressure is used to indicate the strength of a low pressure system while the curvature and gradients in troughs serve to estimate the "strength" of a trough. Minima or trough lines are used to follow the systems for the purposes of extrapolation. However, there are other non-obvious pressure patterns which produce positive and negative values.

4. SUGGESTIONS

Fig. 1 is a sea level map for eastern North America from the Canadian Meteorological Center. The solid lines are the isobars are at every 4 mb. The dashed lines represents sea level geostrophic vorticity, at intervals of 4×10^{-5} s^{-1}, calculated from the analyzed sea level pressure using a centered finite difference scheme with a grid length of 100 km. The result is then smoothed to remove perturbations of 200 km and less. Examining Fig. 1, the region marked by the bold letter A, corresponds neither to a trough or low but contains strong positive values of geostrophic vorticity. Tracking the position and intensity by eye is quire a challenge. The readers are referred to Moffet (1987) and Verret (1990) for discussions of the problems of identifying and calculating laplacians in pressure fields.

The following observations are based on the experience of the author over the last 6 months with the maps at 12 hour intervals of the type shown in Fig. 1:

1) Pattern recognition of the sign laplacian of sea level pressure can be very tricky and the intensity is often extremely difficult to guess.

2) Usually vorticity values increase as lows deepen, but often enough the opposite may occur, i.e., the geostrophic vorticity increases while at the same time the low fills. This usually is produced by one of the two following mechanisms: the high pressure systems that surround the low build or the diameter of the low (its scale) decreases.

3) Some maxima of geostrophic vorticity that would not be identified as classical systems such as lows or troughs are easily on these maps.

4) Classical secondary coastal developments seem to show up as new vorticity maxima along the coast 12 hours before the development occurs in the classical sense.

These observations indicate some of the potential operational use of these fields and suggest that one of the reasons that meteorologists require years of experience in order to analyze and forecast the weather is that the ability must be developed to recognize patterns of positive and negative laplacians often without realizing what one is looking for. A series of maps of the type in Fig. 1 will be shown in the poster session

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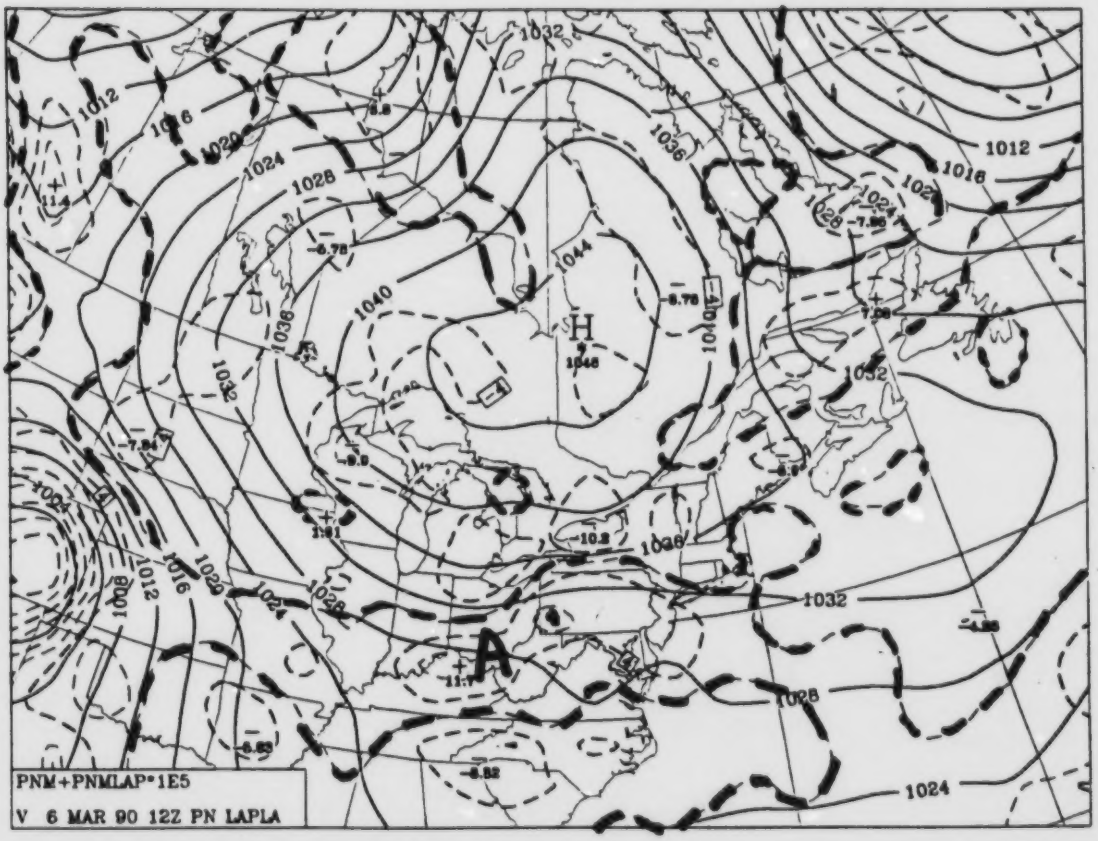

Figure 1. Sea level map for 6 March 1990 at 12Z. Solid lines are isobars at every 4 mb. Dashed lines are constant geostrophic vorticity isopleths at ever $4x10^{-5}$ s^{-1}. The zero line is the thick dashed line. The zone of positive values oriented east west through the letter A (N.J.,Pa., Ken., Miss.) was analyzed at a stationary front on classical maps. Because of the relatively strong value of geostrophic vorticity (maximum of nearly 12 $x10^{-5}$ s^{-1}), this system was associated with moderate precipitation.

THUNDERSTORMS AND SUPERCELLS WINDSHEAR ENVIRONMENT - CASE STUDY

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ABSTRACT

Recent studies have indicated that windshear in the low levels and buoyancy are important parameters in predicting thunderstorm characteristics. Prior to and during a severe thunderstorm which occurred in Saskatchewan on June 30, 1989, the operational staff attempted to follow the evolution of the wind field near the storm. Data from stations near the storm was extrapolated and estimations were made to approximate the near storm environment. This lab session will reproduce this process, with some elaboration, to evaluate theoretical considerations in an operational setting.

RESUME

Des études récentes ont montré que le cisaillement des vents a basse altitude et l'instabilité convective sone des paramètres importants pour prédire les orages. Avant et pendant le développement d'un orage violent, en Saskatchewan le 30 Juin 1989, l'équipe opérationnele de prévision a essayé de suivre l'évolution du patron des vents près de l'orage. Les données de stations d'observation ont été extrapolée et des estimations ont été faites pou connaitre l'environnement près de l'orage. La session de laboratoire essaiera de reproduire ce processus, avec quelques élaborations, pour évaluer des considérations théoriques dans un cadre opérationnel.

Lab Objective

1. To understand the effects of low level windshear and buoyancy on a severe thunderstorm in western Canada.

2. To extrapolate station data to the near storm environment to better estimate the storm characteristics.

Theory

Thunderstorms have been studied since the late 1800's in order to better understand the physical processes that go on in and around the thunderstorm. The synoptic scale dynamics and thermodynamics are important to provide the proper environment for potential thunderstorm development, but it is the mesoscale dynamics and thermodynamics that differentiate severe convection from non severe convection. Techniques developed by Miller

(1972) in the 1950's are still the first steps taken in determining severe weather potential. These techniques use synoptic scale motion to determine if the environment is conducive to thunderstorm development.

However more recently the importance of windshear and local instability (or potential buoyant energy) in the thunderstorm environment have been recognized by forecasters and numerical modellers. Numerous papers have been written showing the relationship between shear and potential buoyant energy (PBE) and tornadic storms.

Without windshear convective cells would develop but as the precipitation began to fall in the updraft the storm would die because the updraft was cut off by the downdraft created by the falling precipitation. With shear in the atmosphere the updraft becomes tilted and the downdraft is created separately thus the storm through the downdraft can feed itself (through gust fronts) and persist longer. Helicity, which is the dot product of the velocity and vorticity vectors, has been determined by Brooks to be a factor in the development of tornadic storms by increasing the rotation in the low levels thus increasing the updraft strength.

The bulk Richardson number, used by Rasmussen & Wilhelmson (1983) and Weisman & Klemp (1986)to correlate storm development and PBE and windshear below 4 KM. With large bulk Richardson numbers (R>80) there is usually a weak sheared environment so usually only one cell develops and has a short lifespan. If the bulk Richardson number is small (R<10) it is a strongly sheared environment and it is hard for convection to develop. But with moderate bulk Richardson numbers shear values are moderate to strong and PBE is usually large so the two parameters work together in increasing the convective development. Moderate bulk Richardson numbers usually lead to the development of multicellular or supercellular storms. The bulk Richardson number does not indicate the severity of the storm. In storms with large PBE, the updrafts will be strong and large hail may form. In storms that lack PBE, updrafts will be weak so likelihood of hail or tornadic events is small.

Patrick and Keck (1987) showed that the magnitude of the windshear and the curvature of the windshear in the lowest 3 KM AGL where good discriminators of tornadic and non tornadic thunderstorms. Turcotte and Vigneux (1988) also developed as severe storm index (SSI) which also incorporates PBE and windshear to discriminate between severe and non-severe thunderstorms. But again the severity of these events cannot be correlated to the index.

The motion of storms in sheared environments is not allows with the mean flow. Supercell storms will tend to propagate to the right of the mean flow if te winds veer with height. Also the strongest new convection will occur on the right flank when winds veer with height.

The lack of data near a thunderstorm makes the prediction of the thunderstorm that much harder. The environment near the storm is changed by the interaction of the storm and its surrounding

environment. Although we know low level windshear and potential buoyant energy are important for the formation of severe thunderstorms the exact criteria are not likely to be observed due to the large gaps in the observing network. However by monitoring the changing environment we can detect small changes that can help lead to the forecasting of severe thunderstorms.

Lab details

This lab will consist of the following activities:

a) examination of the synoptic pattern, both surface and upper air and present and future.

b) examination of the "near" storm environment using surface analysis, radar imagery, satellite pictures and interpolation between station data.

c) examination of storm indices and how they changed during the evolution of the storm (i.e. Bulk Richardson number, Rasmussen shear, helicity, Lifted index, and Severe Storm Index).

Storm event details

Storm track, damage reports, and damage from other storms which were in close association with the storm under study will be presented.

Conclusions

From examination of this severe thunderstorm event we are able to conclude several things that are of operational interest. Firstly, the current theory which holds that the shear in the lower troposphere plays a role in the evolution of thunderstorms into severe weather producers, appears to have some validity in this case. Values of Bulk Richardson number, and the shape of the wind profile appeared to converge towards indicators suggested by theory to be associated with super-cell development.

Use of these parameters does appear to have some relevance in a "real-time" forecast operation. The behavior of this storm appeared to justify, at least in part the theory concerning the role of wind shear in thunderstorm development. With this conclusion there are a number of caveats. The first, and most important of this is highlighted by the gaps in the data presented in this study. We see from this that attempts to keep abreast of the real-time evolution of the shear environment near a severe thunderstorm is highly dependent on the quantity and quality of the wind data. The second is that even with close-in data, the interaction of other nearby storms with the wind environment may distort the shear parameters away from what theory would suggest. Finally, during the attempt to follow this storm in real-time, considerable difficulty was experienced in computing the necessary parameters from the point of view of timeliness. This once again argues the necessity for sophisticated automated procedures for real-time operational support of the severe weather forecasting function.

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OPERATIONAL LAKE EFFECT SNOW FORECASTING IN ONTARIO

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Abstract

Lake effect snow is a frequent occurrence in the Great Lakes area beginning in late autumn and continuing through the winter. In Ontario, lake effect snow accounts for a significant percentage of the total seasonal snowfall in areas to the lee of Lakes Superior, Huron, Georgian Bay, and to a lesser extent Lakes Ontario, and Erie. Lake effect snow forms as the result of low level instability. Snow bands form when very cold air crosses relatively warm bodies of water. Although most major lake effect snow bands are associated with clouds topped from 1.5 to 3.0 km, significant snow can fall from clouds topped below 1.0 km.

A classification of the various types of lake effect snow based on stability and vertical lifting criteria is presented. The meteorological assessment of lake effect snow potential is based upon forecast procedures currently in use at the Ontario Weather Centre. The assessment is based upon meteorological conditions which have been found to be conducive to the occurrence of lake effect snow. The application of these forecast techniques will be used to produce a snow forecast from a pre-selected case from the winter of 1989-90.

1. INTRODUCTION

Circulation induced snow (commonly referred to as "lake effect snow" in the Great Lakes area) accounts for a significant percentage of the total seasonal snowfall in many parts of Canada situated near large bodies of water. Locations along the downwind sides of the Great Lakes generally receive two to three times more snowfall each winter than do adjacent locations upwind from the Great Lakes (Braham and Kelly, 1982). Orographic effects also add to the impact of circulation induced snow.

Lake effect snow forms as cold air crosses a relatively warm body of water. The difference in temperature between the water surface and the overlying airmass determines the potential for lake effect snow. Most major lake effect storms occur during the late autumn and early winter months when the waters of the Great Lakes are still a few degrees above freezing. Significant ice cover frequently develops across the lake surfaces by the end of the month of January and as such, the severity of lake effect snow storms diminishes.

2. LAKE EFFECT SNOW SYNOPTIC TYPES

The combination of several factors produces meteorological conditions conducive to the generation of significant lake effect snow. Dockus (1985) has described three different lake effect snow types dependent upon dynamic and thermodynamic factors.

a) "Pure lake effect snow"

This is probably the most common type of lake effect snow. Pure lake effect snow generally occurs once a relatively cold airmass becomes established across the Great Lakes, well after the passage of a weather disturbance. It occurs with a strong temperature contrast between the lake surface and overlying airmass. Upper level dynamic support is weak or absent (Fig. 1).

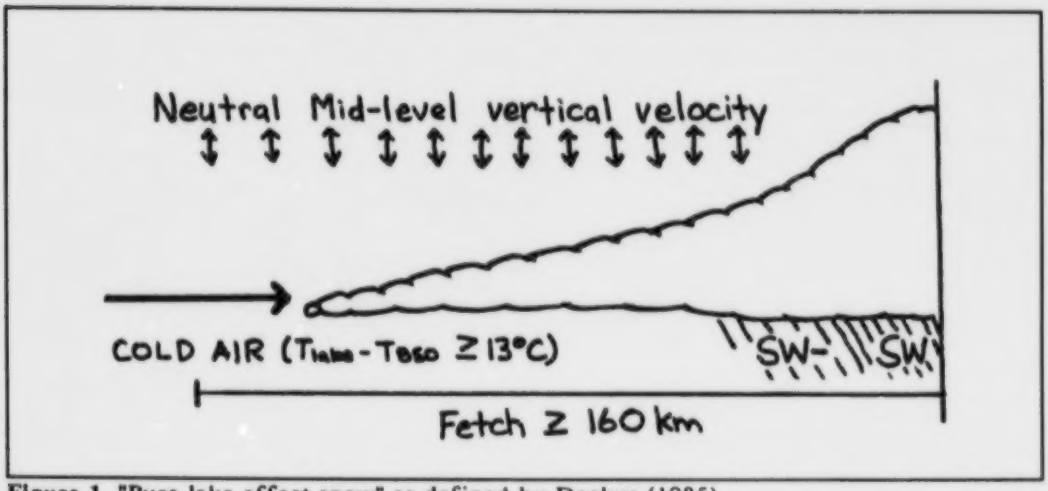

Figure 1. "Pure lake effect snow" as defined by Dockus (1985).

b) "Lake enhanced snow"

Lake enhanced snow is often observed in association with translating weather disturbances, when some dynamic lifting mechanism combines with moderately unstable air over the Great Lakes (Fig. 2).

c) "Combination snow"

The combination of strong low level instability and significant upper level dynamic support produces "combination snow", which can be the most severe of all lake effect snow types. Combination snow usually occurs after a cold airmass becomes well established, and a significant upper impulse (i.e., upper trough or vorticity maxima) moves across a region (Fig. 3).

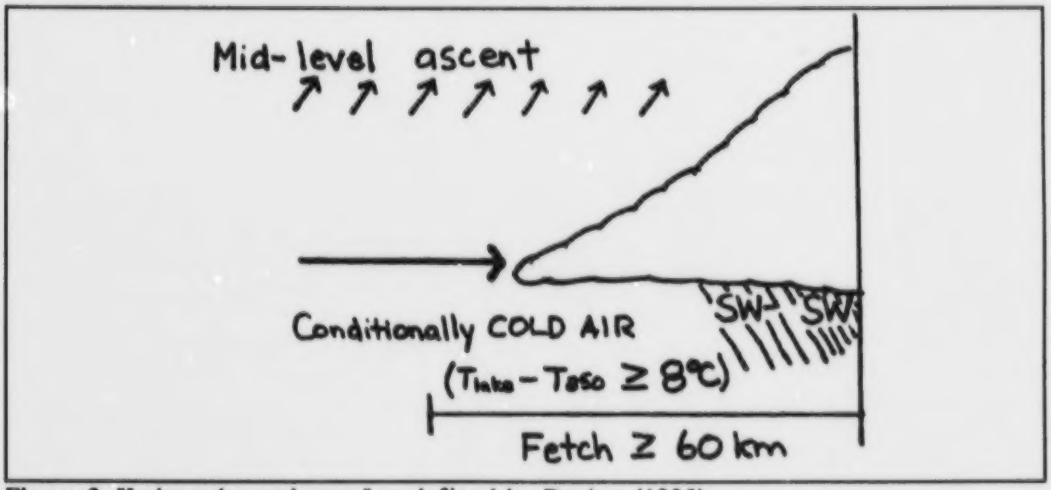

Figure 2. "Lake enhanced snow" as defined by Dockus (1985).

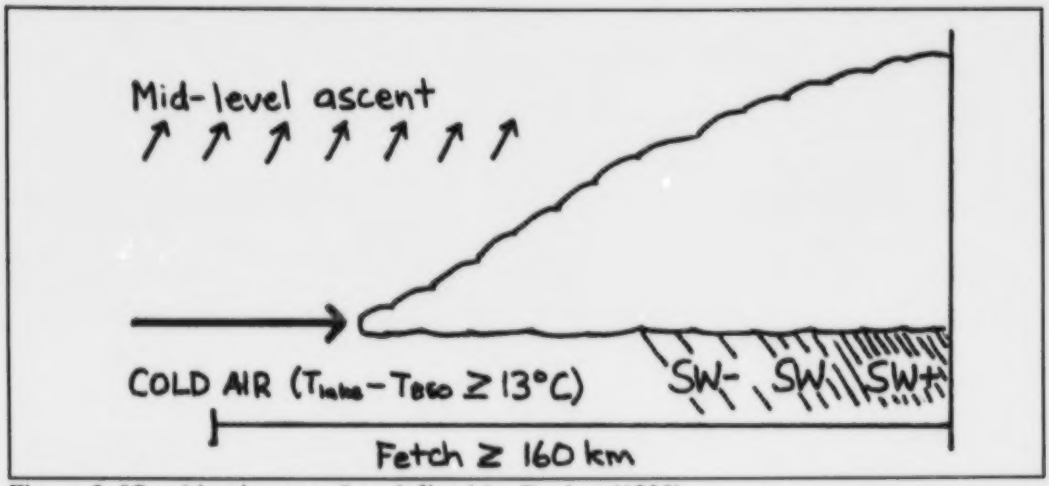

Figure 3. "Combination snow" as defined by Dockus (1985).

4. METEOROLOGICAL ASSESSMENT OF LAKE EFFECT SNOW POTENTIAL

Past studies of lake effect snow storms have determined the meteorological conditions favourable for the development of lake effect snow systems (Niziol, 1987, Dockus, 1985, Murphy, 1989). Assessments of the following conditions must be determined prior to a lake effect snow event.

a) Airmass stability

The airmass crossing the Great Lakes must be cold enough with respect to the water to produce lake effect snow. The forecaster should look for a 13°C difference between the water surface and the 850 mb level ($T_{lk}-T_{850} \geq 13°C$, hereby referred to as "the 13°C rule"). This is roughly equivalent to a dry adiabatic lapse rate in the lowest 1.5 km. However, in the presence of strong upper level support (i.e., "lake enhanced" snow), this temperature threshold may be somewhat less ($T_{lk}-T_{850} \geq 8°C$).

It has also been found that the degree of instability has an impact on snow amounts (Niziol, 1987). With conditional instability (i.e., the 13°C rule barely satisfied), heavy snowfall rates ($\geq$ 2.5 cm hr^{-1}) are only possible with long over-lake trajectories, and some form of upper level ascent. However, it has been noted that with extreme instability ($T_{lk}-T_{850} \geq 20°C$), heavy snowfall rates ($\geq$ 2.5 cm hr^{-1}) are possible with little dependence on fetch or upper level ascent.

b) Low level convergence

In the absence of other processes, a heat source (such as the Great Lakes in winter) results in horizontal convergence, and the development of a cyclonic circulation around the source (Petterssen and Calabrese, 1959). Low level convergence, in the form of thermal troughing and confluence of low level winds, generally occurs with the passage of cold airmasses across the relatively warm waters of the Great Lakes in winter. This is one of the most reliable indications of lake effect storm conditions (Peace et al., 1966; Burrows, 1989). The absence of low level convergence (or the presence of surface anticyclonic isobaric curvature) often implies that strong subsidence is occurring which prevents the development of any significant circulation snow.

c) Upper level dynamics

Upper level dynamic support (upward vertical velocity) is known to enhance lake effect snow. Forecasters should be alert to weak contour troughs which occasionally show up at mid-levels (500 mb), for these may significantly enhance lake effect snow activity (Jiusto, et al., 1970). However, strong subsidence can act to prevent the development of lake effect snow even if other factors favour snow squall development.

d) Fetch across open water

One question in which the forecaster must address, is whether or not the fetch of cold air across the open water surface is long enough to produce significant lake effect snow. Dockus (1985) suggests that a fetch length of 160 km is required to produce "pure lake effect snow". In the instance of "lake enhanced snow", only a 60 km fetch is required to initiate the activity. The low level winds above the mixing layer (850-950 mb) are generally accepted to be representative of the steering level for lake induced snow, and should be used to determine the fetch across open water.

e) Low level directional wind shear

Forecasters in the Great Lakes region have found empirically that significant directional wind shear in the vertical (i.e., > 30°) is detrimental to the maintenance of well organized circulation snow squalls (Niziol, 1987). Increasing directional wind shear leads to a spreading out of single intense snow bands into multiple but less intense bands. Extreme wind shear (i.e., > 60°), tends to cause banded structure to break down completely, resulting in only a few light flurries. The forecaster should determine the degree of directional wind shear in producing the lake effect snow forecast, remembering that the most significant lake effect storms occur with little or no directional wind shear below 700 mb.

f) Low level inversions

Most significant lake effect snow occurs with the low level inversion based at 1 km or higher. If the height of the low level inversion is based below 1 km, then lake effect snow is unlikely unless: a) an large temperature difference exists between the lake surface and 850 mb (i.e., $\geq$ 20°C), and b) the winds are well aligned below the inversion with a long over-lake trajectory. The Great Lakes can significantly modify the inversion height. Forecasters are advised to use caution when using soundings upwind from the Great Lakes.

g) Shifting low level winds

An accurate forecast of low level wind conditions is imperative in the production of good lake effect snow forecasts. The winds between 850-950 mb (and not the surface winds) are accepted to be representative of the steering level. The forecaster must decide whether or not there will be any shifting of the low level winds. Shifting winds will cause bands to meander, and cut down on total snowfall accumulations.

h) Shoreline configurations

Under a constant pressure gradient, air flowing across a land mass will be deflected more to the left of geostrophic flow than air flowing across a body of water due to the fact that surface drag is greater over land than over water. Therefore, frictionally-induced shoreline convergence occurs when the wind blows along a shoreline with land to the right looking downwind. Thermally-induced convergence generally occurs along the centre lines of lakes, downwind from bays, and downwind from sources of thermal pollution (i.e., cities). (Holroyd, 1971). Fig. 4 shows locations of

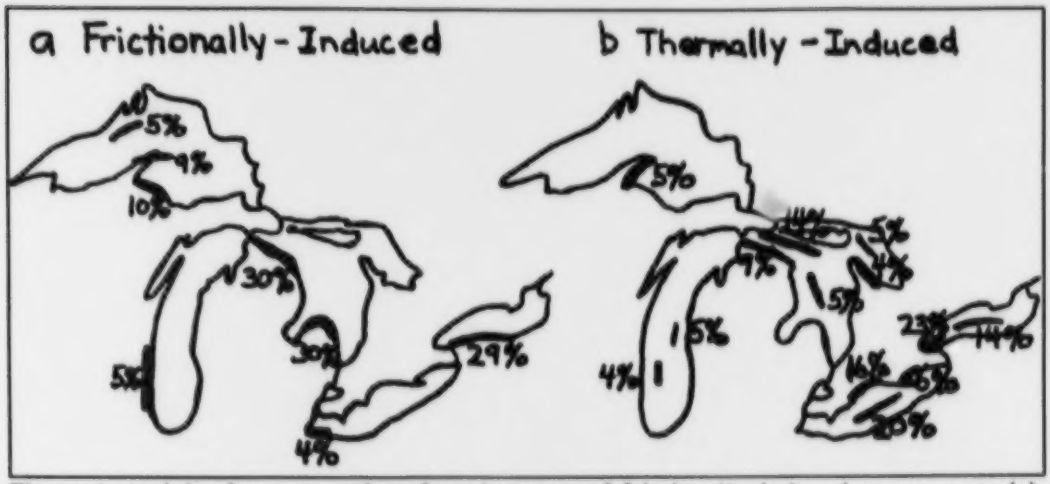

Figure 4. Activity frequency of preferred sources of frictionally-induced convergence (a), and thermally-induced convergence (b). (Holroyd, 1971).

shorelines which produce enlarged lake effect storms by frictionally and thermally-induced shoreline convergence.

i) Wind effects

Strong gusty winds can be almost as significant as the heavy snowfall for causing treacherous travel conditions due to blowing and drifting snow. Whiteouts are a frequent hazard for travellers in the snow belt areas of the Great Lakes. Upper winds taken from the base of the inversion can assist the forecaster in estimating surface wind gusts.

j) Snow band location

Predicting the location of lake effect snow bands may be the most difficult task undertaken by the forecaster. Low level wind direction, shoreline configurations, curvature, and wind shear information must all be taken into effect in forecasting the locations of various snow bands. Shoreline and thermal convergence patterns are also very important in the determination of snow band location as bands will form based on the low level convergence patterns. The magnitude of the low level wind shear will help to determine the snow band type. Snow bands will shift in response to shifting winds. The strength of the wind should de. .e how far inland the snow squalls will move, and how far inland the maximum snow accumulations may be expected.

k) Timing of the onset and ending of snow

The best method for timing the onset and ending of snow squall activity is by the use of thermal relationships. Look for lake effect snow activity to begin when the 13°C rule is satisfied. The ending of lake effect snow can be brought about by different mechanisms. Often, the directional wind shear between the boundary layer and 700 mb becomes too large to support organized lake effect snow after the passage of a low level ridge. Sometimes warm air advection causes the instability to decrease to less than that necessary to produce lake effect snow. However, the forecaster must be alert for the development of "lake enhanced snow" in this situation. Often the lake effect snow persists even after the passage of the surface ridge. This is due to the fact that the winds aloft between 850-950 mb are best representative of the steering flow. The 850 mb ridge position should be used rather than the surface ridge in forecasting the ending of lake effect snow.

l) Location of maximum snowfall

Thompson (1969), observed that under strong wind conditions, the heaviest snow may occur as far as 120 km inland while under light flow conditions, lake effect snow will be confined to areas immediately downwind from the lake. The same effect was noted by Strommen and Harman (1978) to the lee of Lake Michigan.

m) Nowcasting lake effect snow

The forecaster should maintain a close weather watch after the initiation of a lake effect snow event. The surface mesoanalysis is probably the best tool for meteorologists to stay abreast of changes in the mesoscale state of the atmosphere. These should be done as often as possible (preferably every two or three hours) to monitor changes in the orientation of mesotroughs, winds, pressure, temperature, etc., which may effect snow squall behaviour.

Satellite imagery can be helpful in detecting snow bands where radar coverage is inadequate. Visible imagery is often quite useful, while infrared is somewhat less so, as cloud top temperatures of lake effect systems are often similar to the ground temperature.

Doppler radar scans taken at low elevation angles are excellent for detecting lake effect snow. However, the King Doppler is limited in area coverage to a 110 km radius. Low level PPI radar scans for reflectivity can be useful if the precipitation targets are close by, but will overshoot most lake effect cloud tops at distances beyond 100 km.

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SYNOPTIC PATTERN RECOGNITION AND PARTIAL THICKNESS TECHNIQUES AS A TOOL FOR PRECIPITATION TYPES FORECASTING ASSOCIATED WITH A WINTER STORM

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RÉSUMÉ

Une technique de reconnaissance de patron synoptique permettant de déterminer les types dominants de précipitations est presentée. Cette technique consiste à reconnaître certains traits caractéristiques tels: positions relatives et trajectoires des systèmes, gradient et orientation des épaisseurs 1000-500 mb, circulation à 500 mb. D'autre part une méthode objective d'évaluation des types de précipitations est utilisée conjointement. Cette dernière fait appel aux épaisseurs partielles critiques 1000-850 mb et 850-700 mb telles qu'établies par Koolwine(1975)*. Celle-ci est utilisée au Centre météorologique du Québec (C.M.Q.) où quelques ajouts lui ont été apportés: addition d'une valeur d'épaisseur partielle critique, influence du mouvement vertical et du drainage d'air froid par les vents d'est, effets locaux, stage d'évolution d'un système. L'utilisation simultanée de ces deux techniques a conduit à une amélioration globale de la qualité des prévisions émises par le C.M.Q.

ABSTRACT

A synoptic pattern recognition technique allowing the determination of the dominant precipitation types is presented. This technique consists of identifying some caracteristics such as: relative position and tracks of weather systems, gradient and orientation of 1000-500 mb thicknesses, 500 mb circulation. Additionally, an objective technique for precipitation types forecasting is used simultaneously. It calls upon the partial thicknesses 1000-850 mb and 850-700 mb as studied by Koolwine(1975)*. It is used at the Centre météorologique du Québec (C.M.Q.) where a few additional features were identified: an additionnal critical partial thickness value, the influence of vertical motion and of cold air advection by easterlies, local effects, stage of development of a system. The simultaneous use of those two techniques led to a global upgrade in the quality of the forecasts issued by the C.M.Q.

1. INTRODUCTION

One of the most challenging problems facing the operational meteorologist in the day to day forecast is the determination of each precipitation type (rain, freezing rain, snow, etc.) associated with a winter storm. In the following, we will present two techniques currently used at the Quebec Weather Center. Both are used simultaneously to decide what will be the precipitation type, what area will be affected and how significant each element will be. The development of such a technique has been made possible since the local management recognized the importance of creating a specialized desk dealing with winter season forecast problems. Since freezing rain is one of the most hazardous weather elements, its forecast must be as accurate as possible.

2. SYNOPTIC PATTERN RECOGNITION TECHNIQUE

2.1 Goals

- Determine at first glance what are going to be the most significant types of precipitation over the Quebec region areas of responsibility.
- Discriminate between a ZR event (freezing rain) and an IP/S event (ice pellet/snow).

2.2 Advantages

- Uses synoptic fields as seen on analysis and prognosis of upper air and MSL charts.
- If numerical prognosis are reasonably good, it may be used up to 48 hours with a great deal of confidence.
- Allows the public forecaster to mention freezing precipitation well in advance and conversely to avoid mentioning ZR when an IP/S situation is diagnosed.

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* Koolwine, T., 1975, Freezing Rain, M.Sc. thesis, Dept. of physics, University of Toronto, 92 p.

2.3 Technique development

This technique was developed by comparing a few winter storms which produced an important ZR area with a few others which resulted in S/IP over southern Quebec, with no important ZR event. In both cases, the critical 1000-500 mb thickness of 540 dam generally delimits the northern edge of the ZR or IP area. However, the impact is highly different: an IP/S case possibly requiring more a snow/blowing snow warning instead of a ZR warning.

A study of these storms over southern Quebec allowed us to find that some synoptic features particular to important ZR storms were different from IP/S storms. Two major synoptic patterns out of six identified are shown below together with a brief description and analysis. Most of the remaining patterns will be presented more or less extensively in the laboratory.

2.4 Description of patterns and analysis

A. IP storm over southwestern Quebec

The recognition of this type of storm does not exclude the possibility of a few hours of very light freezing rain or drizzle as the center of the low passes by, i.e. towards the end of the precipitation episode. It does indicate though that most of the precipitation will fall as snow and ice pellets. Two synoptic patterns of this type were recognized. The following will give details on only one of these two patterns since they differ mainly by the 500 mb circulation, the remaining features being mostly the same.

A.a: Confluent circulation type:

Typical features: (cf. fig. 1. to fig. 4.)

- Strong 500 mb confluent circulation over Quebec.
- Strong 1000-500 mb thickness gradient along the St-Lawrence valley. (NE-SW)
- High pressure system moving over northern Quebec and remaining in this area.
- Surface low or wave moving over extreme southern Quebec or just south of the Quebec border.
- Northeasterly surface winds enhanced by the NW-SE to WNW-ESE orientation of isobars.

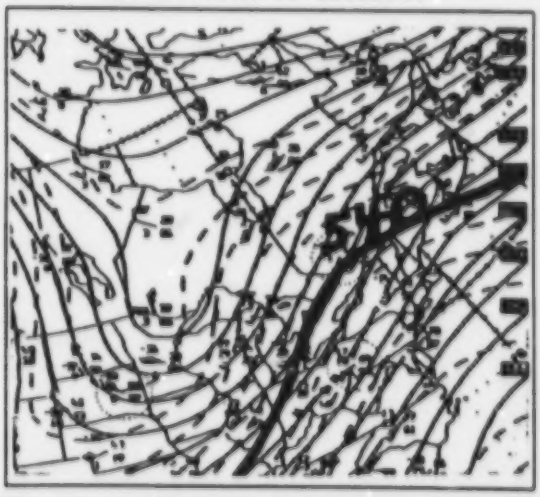

Fig. 1: Confluent circulation type.
500 mb analysis, 10/12/86, 00Z
— — —1000-500 mb thicknesses
————500 mb heights

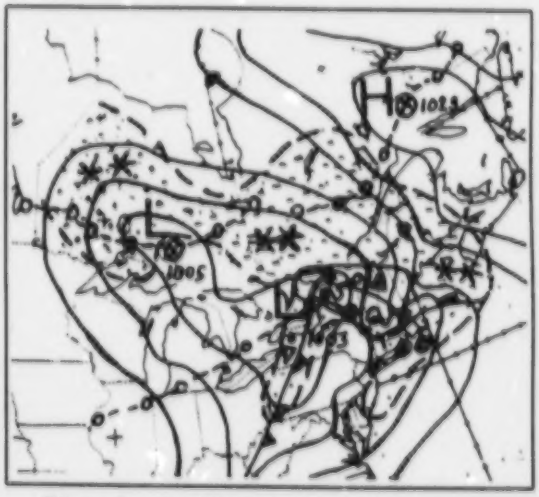

Fig. 2: Confluent circulation type
Surface analysis
10/12/86, 00Z
o--o--o Low/high tracks

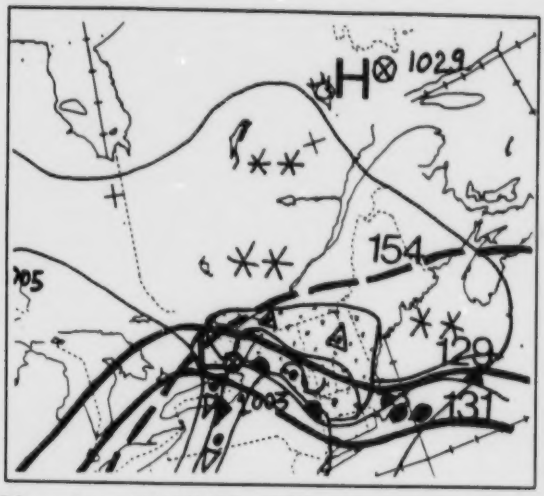

Fig. 3 10/12/86, 00Z: Correlations between precipitation types and partial thicknesses.

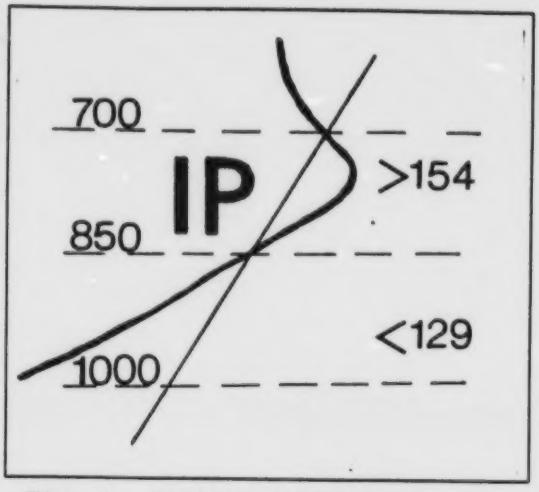

Fig. 4 Typical temperature profile in the IP area.

An analysis of such a synoptic structure shows the following:

- The thickess gradient implies an important surface temperature gradient along the St-Lawrence valley;
- Consequently, with the favourable isobaric gradient, an important low level cold air advection toward the upper St-Lawrence valley is established;
- The 540 dam thickness moving over extreme southwestern Quebec is an indication of warm air with above zero temperatures overrunning this sector.

The result will generally be an IP temperature profile over southwestern Quebec (see fig. 4). The extent of the cold layer trapped at low level will be greater than the shallow warm layer with above zero temperatures (generally well above 850 mb). Moreover, before the arrival of the warm layer aloft, the precipitation will be snow accompanied by moderate to strong northeasterly surface winds generally causing drifting and blowing snow.

That is the reason why this type of situation should be identified well in advance with the help of the numerical prognosis. A good identification will help the forecaster to focus on the most significant weather event. In this case, it might require a snow-blowing snow warning rather than a freezing rain warning even though the 540 dam thickness is forecast in proximity.

B. ZR storm over southwestern Quebec

In comparison to the above IP type, the following case will describe the typical and the more common synoptic set-up for a significant freezing rain event over southern Quebec. Three more synoptic patterns were identified but are not presented here.

B.a: Type ZR: This pattern refers to storms with the normal evolution of precipitation types: S → IP → ZR → R/L

Typical features: (cf. fig. 5. to fig. 8.)

- Moderate to weak N-S gradient of 1000-500 mb thicknesses (when compared to IP cases).

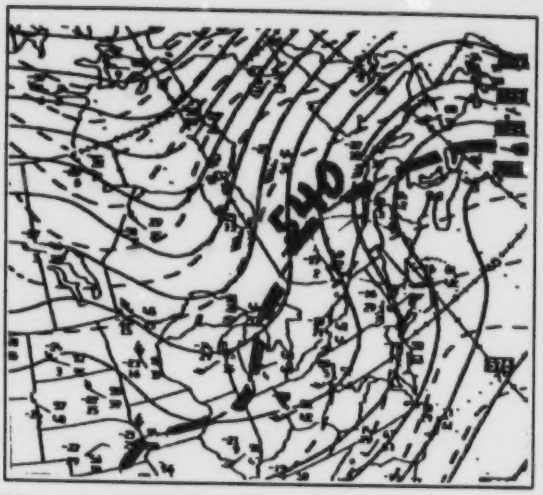

Fig. 5: Classical ZR type.
500 mb analysis, 25/12/86, 12Z
— — —1000-500 mb thicknesses
————500 mb heights

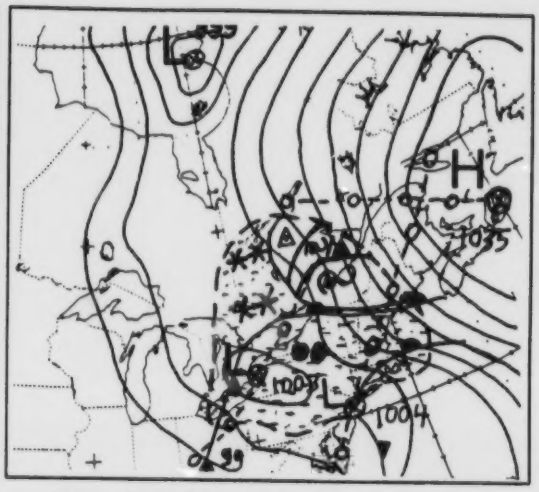

Fig. 6: Classical ZR type.
Surface analysis
25/12/86, 12Z.
o--o--o Low/High tracks

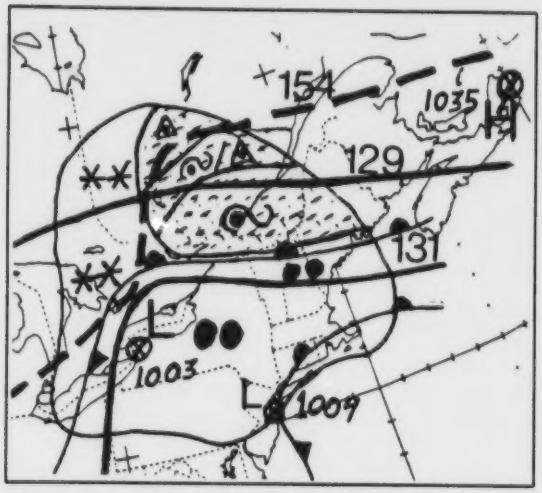

Fig. 7 25/12/86, 12Z: Correlations between precipitation types and partial thicknesses.

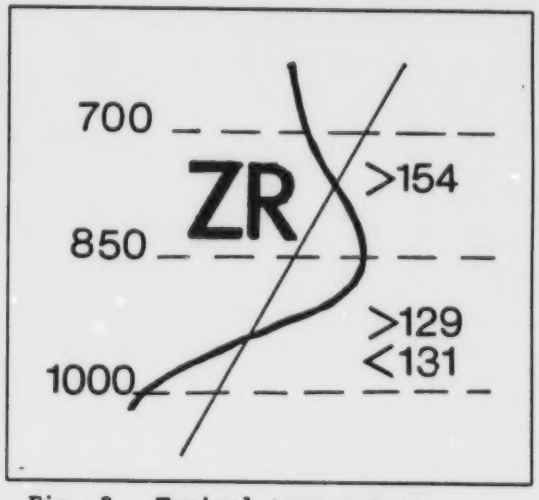

Fig. 8 Typical temperature profile in the ZR area.

- Surface low with a general SW-NE track over southern Quebec or just south of Quebec.
- High pressure system over northern Quebec moving southeastward over Maritimes as precipitation reaches the souhwestern Quebec regions.
- Surface ridge extending northward from the high pressure system.

The important differences between this pattern and the IP patterns are in the track of the high pressure system and in the intensity of the thickness gradient. The high pressure center tracking southeastward to the south of the St-Lawrence and the surface ridge being oriented more northward than northwestward or even westward allow the isobars to be more north-south throughout the St-Lawrence valley which is an orientation less favourable

to strong northeasterly winds. Also, this type of relative positioning of the systems results in a weaker thickness gradient along the valley than in the IP patterns and causes the orientation of the thicknesses to be more east-west than southeast-northwest. These caracteristics imply:

- a weaker temperature gradient along the valley.
- a weaker low level cold air advection because of weaker northeasterly winds.
- a circulation much more favourable to warm air advection at all levels.

In these situations, we will generally obtain a deeper and more extensive warm layer aloft as well as a shallower cold layer near the surface, which will give a typical ZR temperature profile (cf. fig. 8.). Even though the northeasterly winds are weak, they will persist in the valley as long as there is a pressure gradient with higher pressure eastward. The result is a warm front with a slow northward motion thus enhancing the freezing rain period in the regions along the valley.

2.5. Conclusion

Obviously, not all storms can be classified in one of the major synoptic patterns identified. Nevertheless, it does help in many cases to determine the dominant types of precipitation associated with a storm. When used with the partial thickness technique presented below it greatly assists the decision process when forecasting precipitation type.

3. PARTIAL THICKNESS TECHNIQUE

3.1 Goals

- Define precisely the position of each type of precipitation related to a low.
- Determine if a freezing rain warning is necessary.

3.2 Advantage

- Uses shallower thicknesses than the traditional 1000-500 mb thicknesses allowing a better resolution in the vertical temperature profile.

3.3 Technique development and description

T. Koolwine, in his master thesis, found that critical partial thicknesses associated with freezing precipitation over southern Ontario generally fall within certain critical values. For obvious reasons the 1000-850 mb and 850-700 mb thicknesses were used as predictors of low level cold air and mid level warm air respectively. He found that for freezing precipitation both of the following conditions need to be satisfied:

$$\text{1000-850 mb thickness} < 1314 \pm 6 \text{ m}$$
$$\text{850-700 mb thickness} > 1539 \pm 3 \text{ m}$$

After studying a few freezing rain cases, D. Bachand* found that these critical values seemed to be valid over the Quebec region as well. For convenience, he used the values 131 dam and 154 dam. He also found a second low level critical thickness value at which, for a 850-700 mb thickness greater than 154 dam, freezing rain would change to ice pellet. This second critical 1000-850 mb thickness is 129 dam (refer to figs. 3, 4, 7 and 8) to see how these critical thicknesses generally correlate to precipitation types and temperature profiles).

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* D. Bachand, 1986, Unpublished notes on freezing rain forecast with partial thicknesses, Quebec Weather Center.

It is important to note that in the presence of a low level temperature inversion (generally ahead of a warm front) a 850-700 mb thickness greater than 154 dam implies temperature greater than zero somewhere within that layer and that, similarly, a 1000-850 mb thickness greater than 129 dam implies temperature greater than zero below 850 mb. Conversely, in a low level temperature inversion situation, a 1000-850 mb thickness smaller than 129 dam implies that all the layer 1000-850 mb is at a temperature below the freezing mark with a rather cold surface temperature. The latter indicates an ice pellet situation associated with a warm layer above 850 mb.

A. Cantin studied most of the freezing rain and/or ice pellet producing storms of the 1987-1988 winter season as well as a few cases of the 1988-1989 season. The basic conditions stated above seemed to discriminate the freezing rain/ice pellet areas quite nicely, but there were still some exceptions that would fall in and even extend the error margin stated by Koolwine specially for the low level thickness value. The interval 1308 to 1320 for the change of freezing rain to rain is sometimes too large a gap to be used extensively in the operational environment. In the same manner, there is an error margin for the critical value of 129 dam as a threshold for the change of ice pellet to freezing rain.

Something else was then needed to determine more precisely and with more confidence the limits of change of precipitation from one type to another. The examination of all these cases suggested that the intensity of the upward vertical motion related to the intensity of the precipitation was an important parameter to consider in the determination of precipitation type. Stewart and King (1987)** showed clearly this effect with a numerical simulation of precipitation types with different size of snowflakes. The intensity of the cold air advection at low level by easterlies enhanced by the presence of valleys, especially the St-Lawrence, is also important and is related to the intensity of the vertical motion in the boundary layer. The effect of vertical motion on precipitation types according to the researchers and confirmed by observations can be summarized qualitatively as follows:

- increasing upward vertical velocity leads to more solid precipitation type: for example, with the same partial thicknesses or vertical temperature profile, precipitation might change from ZR to IP or from R to S.

- conversely, in a region with a general IP temperature profile, precipitation may be observed as ZR if upward vertical motion and low level cold air advection become weaker or even tend toward zero.

In the following section, the summary of these results is presented in a general table describing the most probable types of precipitation according to the partial thicknesses and to the intensity of the upward vertical velocity and low level cold air advection. The vertical velocity and drainage have not been quantified yet and must be evaluated subjectively by the meteorologist.

3.4 Summary of results

The table 1. summarizes the results, showing the operational correlations as currently used at the Quebec Weather Center. The first part of the table refers to cases where there is no overlapping of the critical thicknesses whereas the second part refers to cases with overlapping of critical thicknesses making freezing precipitation possible.

** Stewart R. E. and P. King, 1987, Freezing precipitation in winter storms, Monthly Weather Review, Vol. 115 No. 7, pp. 1270-1279

Table 1. Precipitation types according to partial thickness intervals and upward vertical velocity (evaluated subjectively).

(): Types between parentheses are possible but not dominant except for those with one of the three specific following conditions:
#1: Warm sector or southerly winds
#2: Close to the 154 dam
#3: Ahead of warm front and >152 dam
X/Y: The two types (or more) are equally possible

	THICKNESS 850-700	THICKNESS 1000-850	PRECIPITATION TYPES Signif. up. V.V. and /or signif. low lvl. cold air advection	Weak up. V.V. and near zero low lvl. cold air advection
WITHOUT OVER-LAPPING	<154	<129	S	S (IP/ZL)
	<154	129-131	S (R #1)	R/S (R #1)
	<154	>131	R	R
WITH OVER-LAPPING	<154	<129	S (IP #2)	S (IP/ZR #2)
	<154	129-131	S/IP (ZR #2) (R #1)	IP/S (R #1) (ZR/ZL #3)
	<154	>131	R	R
	>154	<129	IP (S #2)	ZL/ZR/IP
	>154	129-131	ZR (IP #2)	ZR/ZL (R/L)
	>154	>131	R (often >132)	R

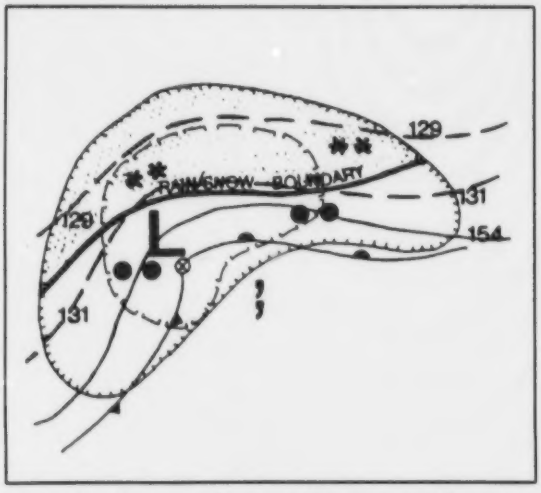

Fig. 9 Mature low without overlapping of the partial thickness lines and associated precipitation types.
▪▪▪▪▪▪▪▪▪▪▪▪ : Precipitation area
▫▫▫▫▫ : Area of strong VV
— — — : 1000-850 mb thickness
——— : 850-700 mb thickness

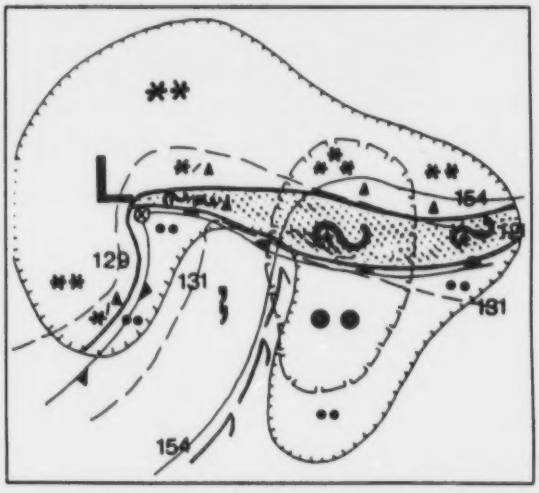

Fig.10 Occluding low with overlapping of the partial thickness lines and associated precipitation types. (same as fig. 9.)

A. Partial thicknesses and precipitation types ahead of a winter storm.

A.a With no overlapping of critical thicknesses.(cf. fig. 9.)

Generally, when there is no overlapping of the critical lines (part 1 of table 1), the R/S boundary will be close to the 131 dam (which is generally just north of the 154 dam) if there is sufficient vertical motion and if the system is not occluded. Otherwise, it could be anywhere between the 129 dam and 131 dam specially if there is a local effect such as a large open water body. In this case the 540 dam has proved to be a good indicator for non-occluded sytems. The 129 dam seems to be the lowest low level thickness value at which liquid precipitation is possible (except for drizzle, freezing or not) and it generally matches the 528 dam 1000-500 mb thickness line.

A.b. With an overlapping of the critical thickness lines.(cf. fig. 10.)

A.b.1: R/ZR boundary:

In cases with strong vertical motion, this boundary is generally between the 131.0 to 131.5 dam and sometimes near the 132 dam. When the vertical motion becomes weaker the boundary will move towards lower thickness values between 131 and 129 dam specially if the low levels cold air advection approaches zero. In the occluded case shown, even though the mid level thickness is lower than 154 dam just ahead of the low north of the warm front the precipitation remains a mixture of very light freezing rain, freezing drizzle and ice pellet. This can be explained as follows: (1) surface winds remain easterly keeping cold air very close to the surface in the boundary layer; (2) precipitation rate is light; (3) the warm air layer is at a lower level, giving a 850-700 mb thickness lower than 154 dam. However, for values lower than 152 dam the airmass becomes unstable and moderate to heavy snow showers is produced instead of light freezing precipitation.

Finally, whatever the thickness values (except if lower than 129 dam), the precipitation will change to rain if the surface winds become southerly breaking up the inversion in the boundary layer. The setting up of southerlies generally marks the arrival of the warm sector.

A.b.2: ZR / IP boundary:

With the 154 dam line north of the 129 dam, the latter generally marks the ZR/IP boundary in a significant vertical motion situation. With weaker vertical motion, the boundary is somewhere between the 154 dam and 129 dam.

A.b.3: IP / S boundary:

This boundary is in most cases indicated by the 154 dam when this line is north of the 129 dam. Otherwise the transition goes from freezing rain to snow with almost no ice pellet area.

B. Partial thicknesses and precipitation types in the wake of a winter storm.

Generally in this area there is no overlapping of the critical thickness lines and the remaining problem is to determine the transition from rain to snow. The vertical motion is also weaker, except in the comma head where snow generally falls, and, as stated above, in these cases the rain-snow boundary can be anywhere between the 129 and 131 dam. Nevertheless, some indications may help determining this boundary:

- The indication of a surface trough trailing the low would be a favoured location since winds ahead of the trough remain south to southwest.

- If a strong west to northwest circulation prevails southwest of the low with no well-marked trough, the boundary will be close to the 131 dam.

If there is overlapping of critical thicknesses, the precipitation, if any, could be of any type depending on the surface temperatures.

C. **Local effects and partial thicknesses technique.**

Some local effects will influence on the types of precipitation that the general correlations would indicate: valleys, mountains and large water bodies are the most important ones.

The presence of a valley tends to push the precipitation types boundaries towards higher low level thicknesses, whereas mountains and large water bodies have the opposite effect. More details on local effects will be discussed in a technical note to be published later.

3.5 Forecast of partial thicknesses.

The numerical forecast partial thicknesses have improved in recent years and can be precise enough to be used operationally. A verification of the forecast partial thicknesses from the RFE model was made for all freezing precipitation producing storms of the 1987-1988 winter. Unfortunately, a new version of this model was implemented by december 1988 and the RFE model has shown a significant cool bias ever since. The partial thicknesses from the canadian spectral model V9 were used since then and have shown to perform well during the 1988-1989 winter and again this current winter with very little error up to 24 and even 36 hours (in most cases).

3.6 Simultaneous use of partial thicknesses and pattern recognition

The partial thickness technique helps define precisely which region will be affected by freezing rain. On the other hand, the pattern recognition technique may help in the evaluation of the accuracy of the forecast partial thicknesses and it helps adjust them in some cases, especially for longer term forecast (i.e. 36-48 hours). For instance, if an IP case is identified while the forecast partial thicknesses would suggest freezing rain, we can suspect that the partial thicknesses are forecast too far north, particularly at low level. Even with a very good surface numerical prognosis, this may happen due to presence of strong cold air advection in the boundary layer. This latter effect is generally underestimated allowing thicknesses to rise faster in the model than in reality. The pattern recognition technique, combined with the partial thicknesses, gives very good results in many cases.

4. CONCLUSION

The synoptic pattern recognition technique and the partial thickness technique should be used simultaneously to determine the precipitation types associated with a winter storm in the day to day forecast. Both the synoptic and the mesoscale effects are more or less considered by these techniques and we strongly believe that their use at the Centre météorologique du Québec by the winter severe weather specialists has raised significantly the overall quality of the forecasts.

The synoptic pattern recognition technique requires local application but we believe a similar approach could and should be developed in each region. The partial thickness technique is, on the other hand, more general and based on the physical structure of the atmosphere making its application possible almost anywhere with some minor adjustments.

BRIDGING THE GAP BETWEEN RESEARCH AND OPERATIONAL METEOROLOGY: A SUCCESS STORY IN OKLAHOMA

By

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A B S T R A C T

Nearly 10 years ago, the University of Oklahoma and the National Oceanic and Atmospheric Administration proposed to create a "Weather Center" from the theoretical, applied and mission-oriented units in central Oklahoma. A prime purpose of this Center was to reduce the time between basic research and its operational applications. The basic foundation for success involved a lengthy commitment to applied research, job-centered training, self-evaluation, and frequent interaction across related disciplines. A prime goal was to improve the information assimilation and decision-making capability of NWS forecasters.

R É S U M É

Voilà près de 10 ans, l'université d'Oklahoma et le "National Oceanic and Atmospheric Administration" proposèrent de créer un "Centre Météorologique" à partir des diverses unités de météorologie théorique et appliquée de l'Oklahoma. Un objectif primordial de ce Centre était de réduire les délais entre la recherche et ses applications opérationnelles. Le fondement de la réussite de cette entreprise impliquait un engagement à long terme envers la recherche appliquée, une formation axée sur le travail d'exploitation, une auto-évaluation et beaucoup d'interactions entre les différentes disciplines. Un des buts premiers était d'augmenter la capacité d'assimilation de l'information et de prise de décision des prévisionistes.

I. INTRODUCTION

Over the years, the emergence of centers of high technology around the United States has not been a matter of happenstance. Most have centered around strong research universities and/or a collection of government sponsored research laboratories. They often embraced research interests that spanned a broad continuum from very theoretical "basic science" laboratories to the very applied mission-oriented operational units.

As the last decade began, the often-independent meteorological groups located in central Oklahoma were heavily involved in high

* Formerly NWS Area Manager for Oklahoma

technological pursuits involving computers, software development, sophisticated radars, satellites and a commitment to both basic and applied scientific research. While relatively small by U. S. national standards, this meteorological aggregate was poised for synergistic growth--with proper encouragement--to achieve national and international recognition for the relevance of its combined activities.

It was within this framework that the University of Oklahoma (OU) and the National Oceanic and Atmospheric Administration (NOAA) proposed to create a "Weather Center" from existing groups in central Oklahoma. Included would be the broad spectrum of:

- theoretical and applied scientists from the University's School of Meteorology, the OU-NOAA Cooperative Institute for Mesoscale Meteorological Studies (CIMMS), and the National Severe Storms Laboratory(NSSL); and

- mission-oriented practitioners at the National Weather Service Forecast Office (WSFO), the Interim Operational Test Facility for the Next Generation Radar (NEXRAD) and the Oklahoma Climatological Survey (OCS).

So constructed, the Norman/NOAA Weather Center would be unique in that an operational WSFO, a major national research laboratory and a strong university program in meteorology would be included.

A second important consideration centered on Oklahoma's very high frequency of tornadoes, hail storms, damaging winds, and flash-flood producing rainstorms. The collective vision believed a co-location of research and operational groups in this natural meteorological laboratory would serve as the unifying factor to assure close cooperation between theoretician and practitioner.

Some 5-6 years later (in January 1987), the National Weather Service (NWS) of the United States moved its State Forecast Office for Oklahoma to the North Campus of The University of Oklahoma. At the same time, NOAA also established a permanent base of operational support (OSF) for the international NEXRAD Program. The purpose of that move and the establishment of a Norman-based support fac[illegible]ty was six-fold:

- to reduce the time it takes new technologies emerging from basic research to become operational--with the first major "targets of opportunity" to assure a smooth and effective implementation of NEXRAD and other Advanced Weather Information Processing Systems (AWIPS);

- to increase the awareness by theoreticians of operational problems;

- to improve the capability to acquire, test and evaluate remote sensing devices in both laboratory and operational environments;

- to provide opportunities for graduate and continuing meteorological education for personnel of the Weather Center Units;

- to increase the likelihood that thesis and dissertation research would focus on NOAA/NWS problems; and

- to develop a new generation of meteorologists who were well educated in theory and application, had been exposed to the latest state-of-the-art equipment, and thus, were fully prepared for the technological advances of the future.

It was indeed visionary that the entire congressional delegation from the State of Oklahoma desired to "provide the research and operational base to attain significant improvement in regional and local weather services" in order for "the vast improvement in weather services and technologies developed in this center ... [to] ... directly benefit the entire nation"*.

The purpose of this manuscript is to document achievements that resulted from a formal establishment of the Norman/NOAA Weather Center and to provide the reader with a status report on this visible attempt to bridge the gap between research and operational meteorology.

This report documents the "foundation for success" that underpins an experimental-like forecast center in Oklahoma (Section II), provides primitive solutions to **THE** operational problem of the 1990s--namely, data overload (Section III), summarizes interactions that occur routinely between theoreticians and practitioners in central Oklahoma (Section IV), and closes with final observations about the "gap" between research and operational meteorology (Section V).

II. THE BASIC FOUNDATION FOR SUCCESS

As a result of growing demands by changing radar technology at the WSFO in Norman, four significant events occurred during the spring of 1983:

- a structured warning-verification system was developed (Bunting and Crawford, 1990);

- a rigorous, in-house training program (spanning 4-5 years) was organized;

- the "Devore Table" was published (Devore, 1983) which "calibrated" new forms of pre-NEXRAD data with the

* Jointly-signed memo to the NOAA Administrator in November 1983

atmosphere; and

- the local network radar began operations in a semi-automated mode, collecting digital data in a NEXRAD-like fashion and ending over two decades of all-manual radar operations.

Details of this basic foundation for success are provided below.

Warning Verification and Applied Research

The prime mission of the NWS is to provide timely, site-specific and highly accurate warnings of impending severe weather events. Since the basic form of available radar data was undergoing a major transformation into processed information, it was imperative that each staff member have a full understanding of the meteorology behind these new data formats and that they become highly efficient at making skillful warning decisions with these new forms of information.

Thus, two operational needs immediately became apparent:

- a warning verification system would be essential if professional growth and improved warning skills were to result; and

- an applied research activity had to begin if the fruits of new technology and the verification system were to result.

Accordingly, a verification system was developed around telephone contacts in each of the 50 counties across central and western Oklahoma that were under the warning-responsibility of WSFO Norman. Figure 1 highlights Garvin County in south central Oklahoma, providing detailed geographic information and--most important--the location of a vast network of informal NWS spotters.

It is these latter contacts--indicated by the dark numbers and ferreted out of telephone information operators, local friends and relatives, and chance meetings one by one--that created opportunities for exhaustive warning-verification efforts. All totaled, the WSFO in Norman has amassed almost 3000 telephone contacts in its 50 county area of warning responsibility since 1983.

With ground-truth information in hand, opportunities opened to study relationships between known severe weather events and new forms of radar information (e.g., Vertically Integrated Liquid [VIL]; Green and Clark, 1971; Devore, 1983). While Devore indicated that storm's possessing VILs greater than 55 gm/kgm were always severe, verification efforts revealed distinct seasonal tendencies to both over-warn and under-warn (Fig. 2).

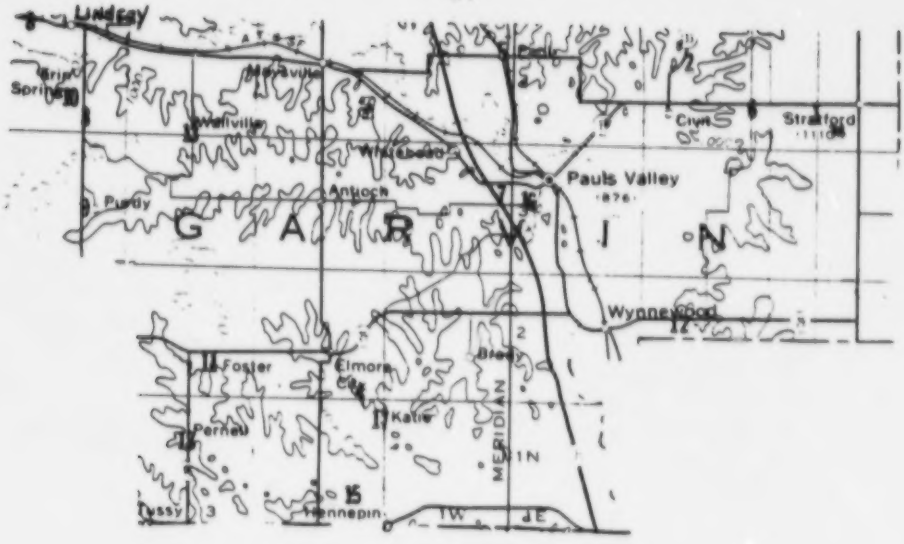

Fig. 1. The geography of Garvin County in south central Oklahoma, indicating the location of significant cities, towns and hamlets. Dark numbers denote the location of informal NWS spotters who live in rural areas. All totaled, approximately 50 telephone contacts are available to the NWS in Norman from this small, rural county.

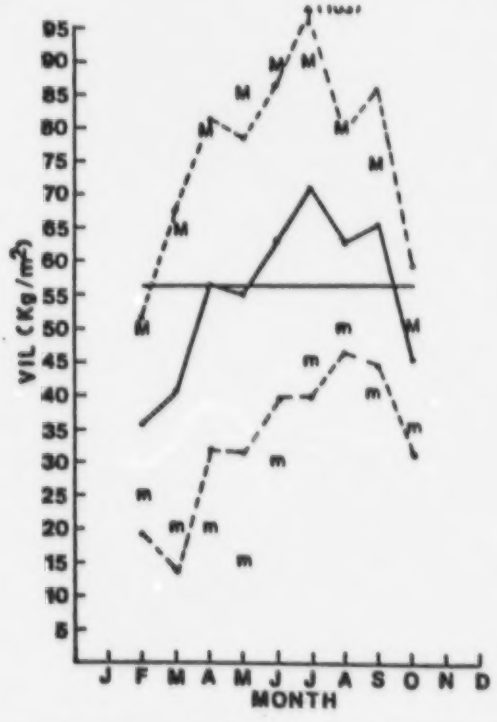

Fig. 2. Monthly variation of the average VIL that accompanied the 351 hail events in the 1983-1984 thesis data set of Beasley (1986).

Several years later, Beasley (1986) documented how improved warning thresholds (related to the seasonal height of the freezing level) could yield more skillful discrimination of severe thunderstorms during the cool season and prevent needless over-warning of borderline severe thunderstorms during warm seasons (Fig. 2).

As a result of extensive warning-verification activities at WSFO Norman since 1983 and the follow-on applied research, WSFO Norman has improved its ability dramatically to discriminate between severe and near-severe thunderstorms. For example, the frequency at which warnings were not followed by severe weather events that occurred in the space/time domain of the warning (Fig. 3) has dropped from just over 0.80 during the early 1980s to approach a very respectable 0.20 in 1989 (Donaldson et al., 1975); even then, it is possible that some remaining warnings still were not "false alarms". However, the key point in Fig. 3 is not the 1989 value of False Alarm Ratio for WSFO Norman; rather, it is the trend toward more skillful warning decisions that has taken 7+ years to achieve!

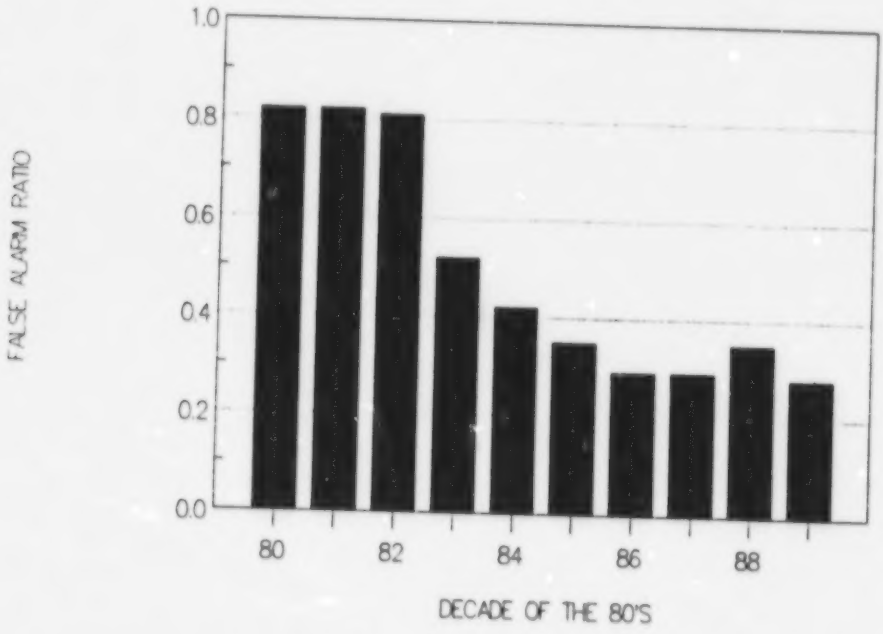

Fig. 3. The False Alarm Ratio (Donaldson et al., 1975) for warning decisions by WSFO Norman during the decade of the 1980s. The important feature to note is the trend downward (toward more skillful decisions) that occurred between 1983 and 1989.

Job-Centered Training: The Vital Shoestring

By the late 1970s, the Forecast Office staff was functioning as an operational test-bed for emerging technologies in radar

meteorology. The WSFO staff already had provided important contributions to the final test results that validated NEXRAD's proof-of-concept. They also were beginning to make routine operational use of digital reflectivity data collected in a pre-NEXRAD mode of operation. As NEXRAD momentum grew during the early 1980s, hardware and software additions to the local WSR-57 permitted the WSFO staff to emulate NEXRAD operations. Frequent access to NSSL Doppler information at the WSFO also became a reality (Forsyth et al., 1990).

Rapidly changing technology, in a highly visible and unusually intense work environment, had taken inevitable aim on futuristic operations. The reality that there could be no retreat from this scenario left only one alternative for WSFO Norman: prepare for a future that, in many ways, had already arrived.

In response to these pressures, a rigorous, in-house training program was organized, implemented and refreshed annually in the 4-5 years that followed. The goal was simple: prepare the WSFO staff to make warning decisions in a more skillful and efficient manner using new data sets and operational methodologies that, to a large extent, were still unproven.

As a result, the WSFO staff developed a training program that had the following attributes:

- it would be based upon a strong academic foundation, with a healthy mix of lecture and displaced "real-time" case studies;

- its aim would be job-centered--to equip the WSFO staff to make skillful warning decisions;

- a high degree of accountability would be built into the course--complete with increasing student involvement, a graded "final exam", and simulations of real-time warning events drawn from local data archives;

- the training would aim to be "two-on-one" with required annual refresher courses; and

- as appropriate, the training would draw from local expertise (e.g., NSSL) and, by design, would involve private-sector meteorologists from Oklahoma City.

Thus, unfolded perhaps the most critical of modernization issues: the fact that there is more and better data simply does not mean that the operational meteorologist has an easier job. In fact, just the contrary is true. More data means more interpretation, more necessary knowledge and, in the end, more work to produce better forecasts and warnings. The hardware could not do it by itself. A well-trained human operator must be capable of assimilating futuristic data and turn that data into information upon which to make a skillful decision. Only then will the potential for improved services become a reality.

As Fig. 4 indicates, the road toward improved services involved a lengthy commitment to training, self-evaluation, and re-training.

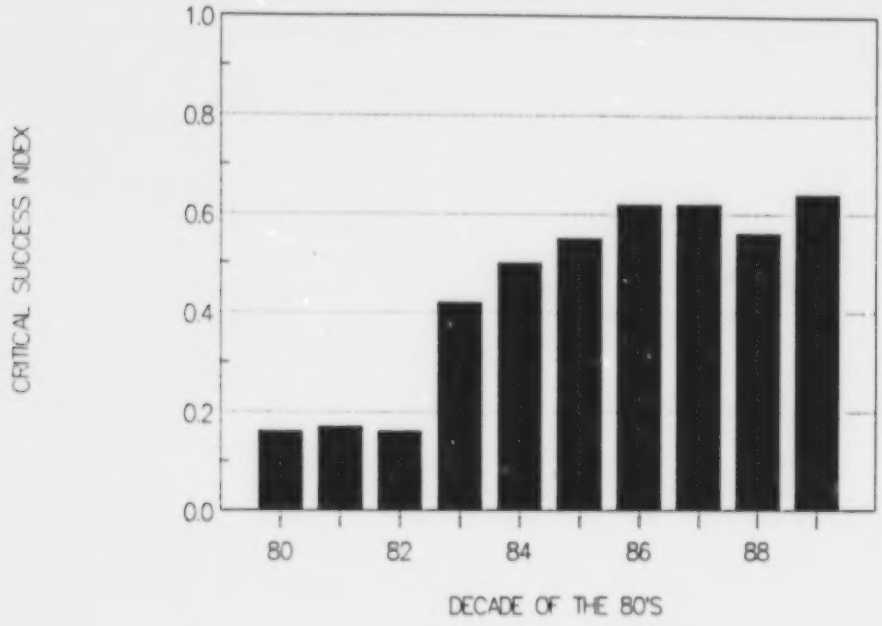

Fig. 4. The Critical Success Index (Donaldson et al., 1975) for warning decisions by WSFO Norman during the decade of the 1980s. While 1.0 indicates perfection, the important feature to note is the steady trend upward that occurred between 1983 and 1989.

III. HARNESSING THE EXPONENTIAL INCREASING DATA VOLUME

As the mid 1980s unfolded, pre-NEXRAD technology became part of the routine through refined operational procedures, thousands of probing telephone calls and appropriately-timed studies. It was at this point that the real operational problems of the coming decade became painfully obvious:

Was it possible for an operational staff to suffocate in a "sea of strange numbers" provided by the arrival of newer and newer technology and its unfamiliar data streams while increasing demands for more skillful forecasts and warnings went unfulfilled? Just exactly who would provide the key that unlocked the future and united new and improved data sets with new and improved services? All signs pointed to the fact that education, training and applied research were the real problems of the 1990s.

Since answers to these questions were difficult, a fledgling effort began between the NOAA/NWS and the University of Oklahoma to focus thesis research on operational problems deemed to have

highest priority. Thus, a series of graduate students began work under a broad umbrella to "improve the information assimilation and decision-making capability for NWS forecasters".

First efforts were aimed implementing the work of Hudson (1970) to extract the maximum diagnostic information from hourly surface data fields. The results (Bothwell, 1985, 1988) produced sophisticated software routines--an AFOS Data Analysis Program or ADAP for short--that ultimately were implemented nationwide.

While new diagnostic products resulted, an "ADAP Decision Tree" was developed (Fig. 5) to aid the forecaster in assimilating pertinent information from these new fields in order to make a better forecast decision for having done so. This entire work, developed in the operational forecast environment of central Oklahoma, likely would have proceeded much more slowly had the author not been granted a brief "sabbatical" assignment to the NOAA Research Laboratories in Boulder.

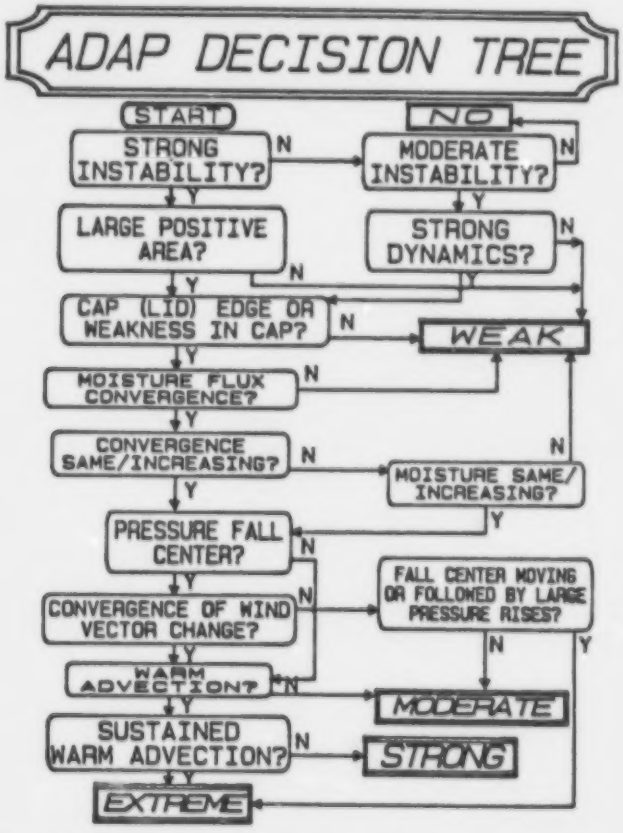

Fig. 5. The "decision tree" used with products generated by the AFOS Data Analysis Program (Bothwell, 1988) to more effectively assess a potential severe weather threat through improved information assimilation by the human forecaster.

Following this lead, Schichtel (1988) and Andra (1990) further attempted to streamline the information assimilation process for the operational staff through their applied winter-weather and severe convective-event studies, respectively.

Anticipating frequently updated low-level wind profiles and improved thermodynamic profiles (both observed and forecast), Schichtel attempted (Fig. 6) to improve the forecasters ability to discriminate between snow, sleet and freezing rain events.

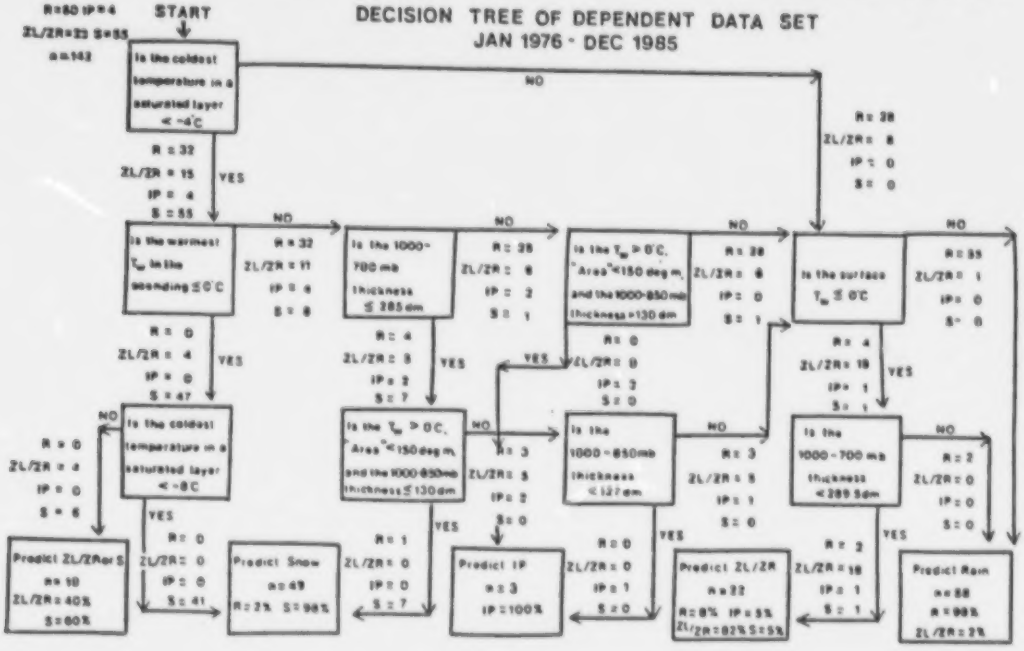

Fig. 6. The winter-weather decision tree developed by Schichtel (1988) to discriminate between snow, sleet and freezing rain.

In a study of severe convective events, Andra (1990) attempted (Fig. 7) to improve the forecaster's ability to extract information from the upper-air diagnostic routines developed by Hoskins et al. (1978) and applied in an operational environment by Barnes (1985) and by Foster (1988).

With the arrival of ADAP routines, large pre-NEXRAD data sets and velocity information from the NSSL Doppler radar, came more information to review at each decision time for a forecast or warning. While the ADAP decision tree and the work of Devore (1983) and Beasley (1986) assisted with decisions internal to NWS operations, a question loomed on the horizon of the Emergency Management community:

What applied research was underway to improve the "readiness posture" by the remainder of the warning system in Oklahoma? What activities would ensure that arriving technology brought noticeable improvements in services at the local community level?

In other words, what was being done to transfer new technology beyond the forecast environment?

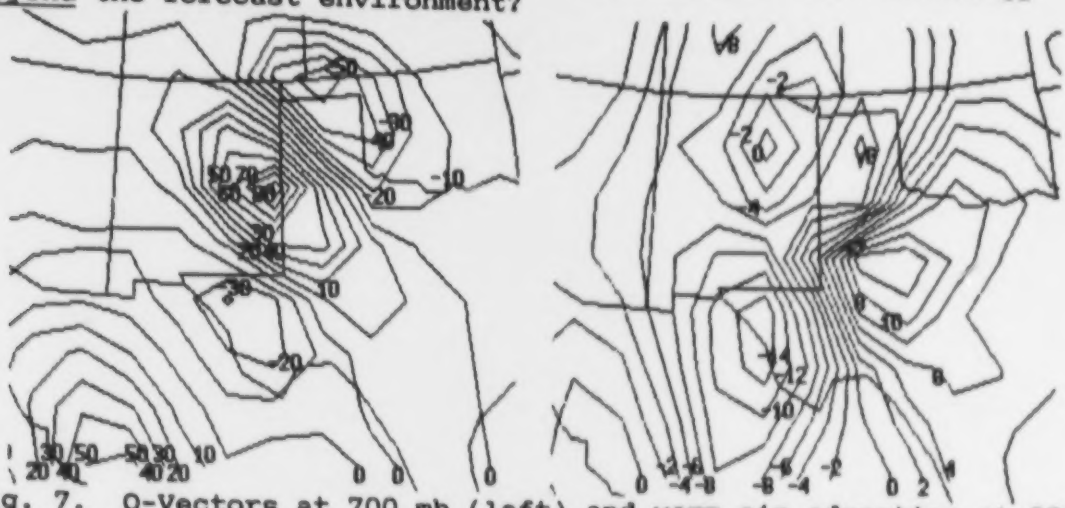

Fig. 7. Q-Vectors at 700 mb (left) and warm air advection at 850 mb from 0000 GMT on 26 April 1984, prior to an F3 tornado and 8 fatalities in east-central Oklahoma at Morris just after 0530 GMT (Andra, 1990). Traditional methods for assessing vertical motion (right) might have focused on eastern Oklahoma. Yet, more complex methods (left) highlighted northwest Oklahoma--the location where an intense squall-line developed as the sun set.

Thus, it seemed appropriate to begin combining data sets to reduce the data redundancy and improve the efficiency of information assimilation by the Forecast Staff. Jackson (1987) proposed combining the best of Bothwell's work (1985, 1988) with the best available from pre-NEXRAD data sets (Figs. 8-9). The goal was to develop products that could be shared graphically with the entire warning team (including NWS and emergency management staff) so that the proper "warning posture" would be achieved before a severe weather episode unfolded.

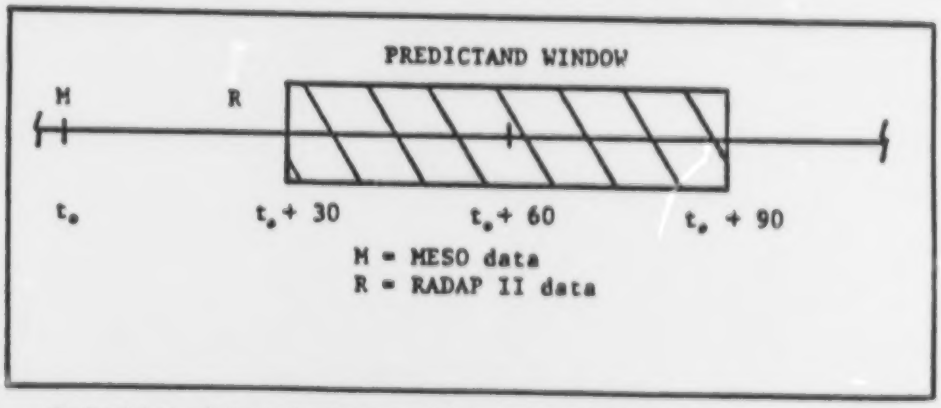

Fig. 8. Relationships between the ADAP (M) and pre-NEXRAD (R) data streams and a predictand time window used to generate 30-90 minute forecasts of impending severe weather (Jackson, 1987).

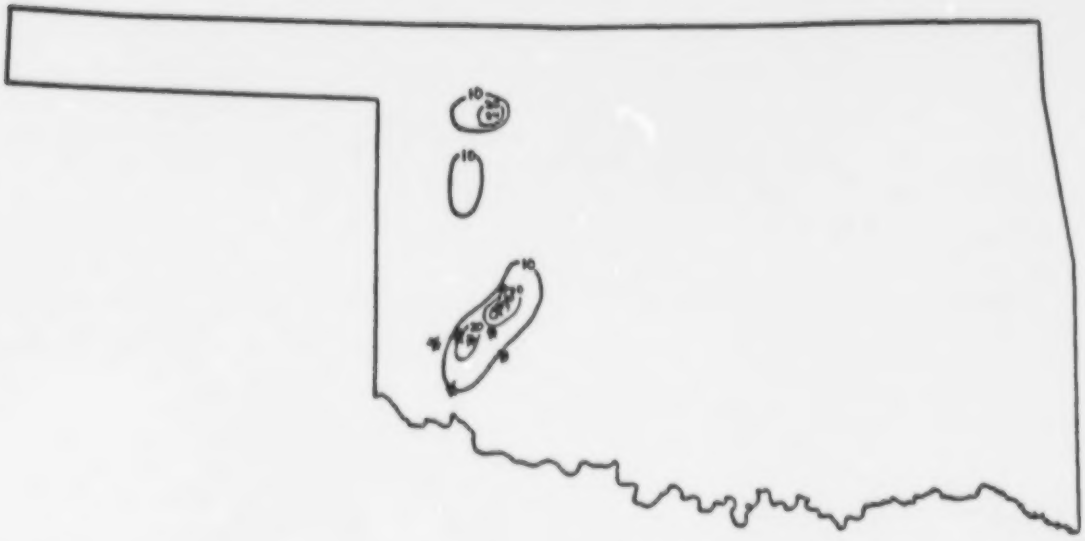

Fig. 9. A graphical-warning product produced by Jackson (1987) that anticipated the possibility of severe hail over western Oklahoma occurring in the 30-90 minute window following data ingest. Asterisks indicate the location of large hail that fell during the forecast period.

If ever a reason existed as to why modern weather technology must move beyond a forecast office, surely that reason was cast in concrete on the night of May 27, 1984--when nearly 15 inches of rain inundated downtown Tulsa OK between midnight and 4 A. M. (Ruthi and Crawford, 1985). The aftermath brought grim statistics indeed: a price tag of 14 lives and $180M in property damage to Tulsa-area residents.

Yet, a crisply worded flood-warning for metropolitan Tulsa was issued at 12 midnight--some 2.5 hours before the devastation peaked. In hindsight, it would seem that the warning system failed on that night!

In the aftermath of that flood event, a radar-based flood warning system was developed (Fig. 10) using pre-NEXRAD technology (Crawford and Andra, 1987). This system, a joint effort by several Federal, State and Local Officials, has operated continuously since April 1986.

No doubt these attempts to reduce data redundancy, retrieve useful information, streamline the decision process and share relevant information with the entire warning team will seem primitive in a few years. Nevertheless, they represent first attempts to combine the applied research talents of our next generation of operational forecasters with the difficult problems faced by today's practitioners.

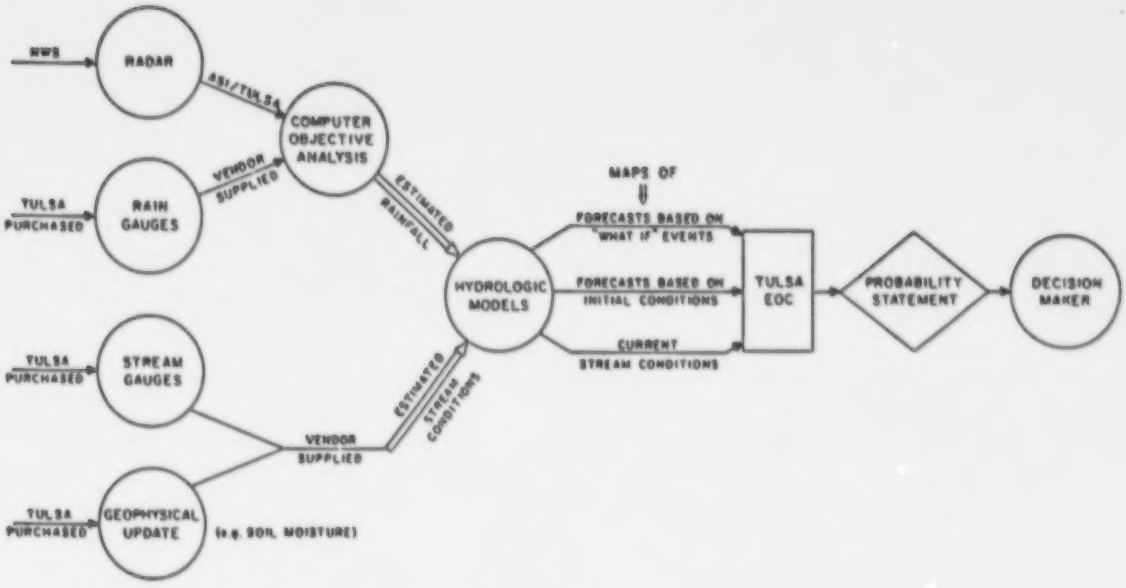

Fig. 10. Schematic Design of the Tulsa Environmental Monitoring and Flood Warning System--as proposed to the Mayor of Tulsa in early 1985. While some facets of the design have not been implemented, the system continues in operation.

IV. ROUTINE INTERACTIONS: INGREDIENT FOR A SUCCESSFUL MARRIAGE

While previous sections of this manuscript provide evidence that a bridge exists between the research and operational arms of meteorology in central Oklahoma, it is the author's belief that the glue holding these activities together is one of mutual respect and trust. These strong feelings permeate activities of the Norman Weather Center primarily because many participants (certainly not all) have walked in each other's shoes.

Those relationships also were fostered through cooperative research and operational programs designed to assist both programs. It is these routine interactions that seems to be the key ingredient in the successful marriage underway in central Oklahoma.

A few notable examples of the routine in central Oklahoma include:

(1) Pre-STORM -- This cooperative research program in 1985 aimed to test the integration of numerous meteorological observing systems leading up to a full-fledged national STORM Program. A team of research and operational meteorologists

issued routine forecasts for the Project. It was during this period that a new NWS product for Oklahoma became routine--the Oklahoma Thunderstorm Outlook.

(2) DOPLIGHT -- This cooperative venture between the WSFO and NSSL resulted in real-time images from the NSSL Doppler being shared with the operational staff each storm season between 1984 and 1988. During the middle DOPLIGHT years, live Doppler displays from the WSFO radar room were shared with the three network television stations in Oklahoma City. The results from DOPLIGHT '87 have been documented by Doswell and Flueck (1989) and by Forsyth et. al. (1990).

(3) MAP -- This spring-time "mesoanalysis project" involved both NSSL and WSFO meteorologists cooperating to issue the Oklahoma Thunderstorm Outlook each day during the prime storm season. It was primarily an activity of 1988.

(4) OT&E-II -- Many eyes in our nation focused on Norman for 5 months during the middle of 1989 as the prototype NEXRAD system manufactured by the UNISYS Corporation underwent a rigorous five month evaluation. Official test results were published by AFOTEC (1989). Additional insight from this important test is contained in Crawford (1990).

(5) QED90 -- During 1990, the WSFO and NSSL will conduct a joint forecast exercise entitled "Quantitative Precipitation Forecast, an Experimental Forecast Demonstration, 1990 (QED90)". This activity will mark first efforts at systematic quantitative precipitation forecasts.

V. FINAL OBSERVATIONS

As a result of joint activities held in Norman since 1983, it is the author's belief that the staff at WSFO Norman has carefully planned for and anticipated the arrival of a progressive, professional and modernized work environment. As a result, the WSFO staff is fully capable of:

(1) visualizing mesoscale processes in four dimensions using conceptual models where appropriate;

(2) filtering relevant information from a copious and often redundant data stream;

(3) meshing a never-ending information stream with that from external sources, even though the external data often my be confusing and sometime irrelevant; and

(4) breaking away from a purely surveillance mode of monitoring evolving weather patterns and jumping into a "problem-solving" mode of operations through more skillful decisions.

For this level of maturity in operations, the WSFO staff owes some of its success to the many cooperative ventures between the scientists at NSSL, the faculty at the University of Oklahoma and to several graduate students who worked on solutions to some important real-world problems.

Surely, it would be safe to say that there is no "gap" between research and operational meteorology in central Oklahoma!

VI. ACKNOWLEDGMENTS

The accomplishments documented in this manuscript were the products of many individuals: Dr. Joe Friday, Director of the NWS, Robert C. Landis, NWS Southern Region Director, and Dr. Ray Jensen, former NWS Regional Director, provided guidance and support--most visibly through the addition of a "technology transfer" meteorologist to the WSFO staff. In addition, the entire WSFO Staff in Norman and Oklahoma City were the epitome of professionalism during these growing and sometimes trying times.

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THE STRATEGIC ROLE OF THE CENTRAL FORECASTING OFFICE IN THE UNITED KINGDOM METEOROLOGICAL SERVICE

by

R.M. Morris (United Kingdom Meteorological Office)

ABSTRACT

Services to the General Public, Industry, Commerce and Civil Aviation are provided by the United Kingdom Meteorological Office through an integrated network consisting of a Central Forecasting Office and a number of regional Weather Centres. A team of experienced senior forecaster sin the CFO provides the Weather Centres with guidance on the interpretation of the UKMO operational Numerical Weather Prediction models, drawing attention to possible defects in the analysis and early forecast frames as well as providing positive advice on the likelihood of occurrence of significant weather elements in the regions. The regional forecasters are expected to fine tune the centralised guidance in preparing forecasts for their customers using their expert local knowledge.

In the future the preparation of forecasts for local customers is likely to become increasingly centralised and more objective and quantitative in format. This will allow the local forecaster to expand his advisory and consultative roles to the benefit of all his customers.

INTRODUCTION

The Central Forecasting Office (CFO) at the Meteorological Office headquarters in Bracknell is a Regional Specialisation Meteorological Centre (RSMC) for WMO and the National Meteorological Centre (NMC) for the United Kingdom. The CFO is also a colocated World Area Forecast Centre (WAFC) and Regional Area Forecast Centre (RAFC) for ICAO.

The CFO is supported by the UKMO operational Numerical Weather Prediction (NWP) models. The global model has a horizontal resolution of about 150 km in middle latitudes and is run twice a day (00 and 12 uct data) producing forecasts up to 6 days ahead. The regional model covers the North Atlantic and Europe, has twice the horizontal resolution of the global model and is run 4 times daily producing forecasts up to 36 hours ahead. Both models have 15 levels in the vertical. A third output, from the Mesoscale model, covers the UK Continental Shelf with a horizontal resolution of 15 km and is run 2 times daily producing forecasts to 18 hours ahead.

The NMC function includes provision of forecasting guidance to a network of Civil Aviation, Public Service and Defence Forecasting Offices throughout the United Kingdom. In the main this guidance consists of descriptive texts, formally structured, issued at fixed times and communicated by teleprinter. In addition there are surface prebaratics in 24 hour steps up to 5 days ahead and a number of significant weather charts (SIGWX) issued which are tailored for aviation and public service needs separately. All charts are sent to the local stations by facsimile. This guidance represents a value adding process which supplements the output from the operational NWP models, most of which is made available directly to the local stations as well as to the CFO. Routine telephone conferences enable the local forecasters to raise specific issues in the guidance and the CFO forecaster is able to stress the most important features in the forecast, particularly to the national radio and television presenters who also take part in the conferences.

The CFO is by far the largest forecasting office within the UK and it contains the most senior forecasters in terms of combined ability, skill, knowledge and experience from within the Meteorological Office.

This paper describes the integrated relationship between the CFO and the combined public service-civil aviation local forecasting offices, as it is now and how it is likely to be in the future.

THE CFO ROLES

Intervention Unit

The CFO has 12 forecasting units manned continuously which are broadly structured into three groups. One group consists of the Intervention team and includes the RAFC forecaster; this group is responsible for ensuring that the NWP operational models have the best possible analyses from which the forecasts start. The role of Intervention is twofold; the NWP data quality control programmes are monitored and if necessary are overriden by the forecasters. This can happen in data sparse areas of the globe especially if there is satellite imagery which supports the forecaster's decision to accept or reject the data. The forecaster is assisted in this role by a listing of biasses for whole data types e.g. SATEMS, SATOBS, AIREPS and SHIP reports. These biasses are calculated by comparing the data type with the NWP model background (ie pre-emptive) analysis over a period of time and can be a very useful source of additional quality control. The most positive role of Intervention is to interpret satellite imagery directly in assessing the NWP model's distribution of cloud and location of thermal gradients. Knowledge of the relationship between geopotential/temperature fields and large scale vertical motion allows the skilled forecaster to fine tune the model analysis to be consistent with the imagery.

Thus the Intervention team provides a detailed assessment of the quality of the NWP analysis and since the data cut off times for the regional and global models are different, the CFO is able to advise on which model has the best analysis. This information is of crucial importance to the users of the NWP model output and can only be provided by the CFO.

Short Period Forecasting Unit

The second group is the Short Period Forecasting Unit (SPFU) which embraces national civil aviation requirements and also includes a small cell that monitors, interprets and predicts evolution in satellite and radar imagery. in essence this group covers the forecast period up to about 15 hours ahead and attempts to predict the evolution of cloud and SIGWX as precisely as possible. The satellite and radar monitoring cell calculates cloud and precipitation motion vectors, cloud top temperatures and precipitation intensities for most of the UK every half hour. Forecasts up to 6 hours ahead are also calculated using techniques ranging from simple extrapolation to sophisticated interactive methods combining very short period forecasts from the NWP Mesoscale model with the observed SIGWX (this enables the forecaster to take into account topographical, diurnal, dynamical and physical effects in the prediction; in essence he is fine tuning the direct model forecasts). Although these forecasts, produced hourly, are available in the CFO they are available to a small number of the local forecasting offices only at present. Wider distribution is effected by converting the forecasts in to text for teleprinter broadcast. Clearly these forecasts are provided more efficiently and effectively in a centralised location and especially in the CFO where an evaluation of the NWP output is readily available for optimisation of the forecasts.

Two charts are prepared and issued by the SPFU to cover the remainder of the period. One is a forecast SIGWX below FL150 over the UK for civil aviation and the other is a similar chart focussed on weather elements important for public service. Each chart is accompanied by a text which contains an evaluation of probability of occurrence of specific weather hazards. These charts are constructed from an interpretation of the whole range of NWP model output available to the CFO. The evaluation of the NWP model output is based partly on information provided by the Intervention Team and partly on a comparison of the early frames of the NWP forecast with the latest observations, including satellite imagery. For example on a day when development of convection overland is very important for the prediction of thunderstorms, model forecast vertical profiles of temperature and dew point for each hour may be inspected on the VDU and compared with satellite and radar imagery and also observations received from stations in the areas of interest. (In principle this exercise can and should also be carried out by the local forecasting offices as well). The SPFU will also take into account known deficiencies in the physical parametrisation and observed biasses in the NWP models.

Public Service Unit

The third group is devoted entirely to the issue of guidance for public service forecasting and consists of the Chief forecaster, directly responsible for the period up to 30-36 hours ahead, the medium range forecaster who covers the period 2-5 days ahead, the medium range forecaster who is responsible for the issue of standard forecasts for the UK Continental Shelf and the eastern North Atlantic Ocean. The Chief works to a 6 hour cycle, evaluating and interpreting the latest NWP regional model output to prepare textual guidance in four distinct parts plus a 24 hour prebaratic (essentially a fine tuning of the model forecast). The first text is scheduled to reach the local forecasting offices at about the same time as they receive the NWP model charts and is probably the most important information they want from him! Does he believe the mode's forecaster? He comments on the analysis, gives an opinion on the forecast evolution in general and adds information about the frontal structure and precipitation. This task has to be carried out quickly and requires close consultation between the three main teams in the CFO. As well as the aspects of evaluation referred to above, the Chief will compare the model output with earlier outputs and attempt to pinpoint sources of difference. He will also compare the regional model with the global and mesoscale model solutions. In succeeding texts the Chief will expand on his interpretation and evaluation and he will also give his own reasoned explanation for the dynamical and physical evolution of the weather systems as simulated by the NWP model - no mean feat under pressure of time constraints!

The Medium Range forecaster works to a similar formula but on a 12 hour cycle. He interprets the frontal positions from the global model output and adds them to the prebaratics, other changes being only cosmetic. Unlike the shorter forecast period, for which local forecasters may feel they have a viable alternative, NWP medium range forecasts have reached a sustained quality well above what can be produced by even the best of forecasters independently. Nevertheless even these forecasts can go wrong and the task of the medium range forecaster is to evaluate confidence in the NWP product. He has a systematic approach to this task; he maintains a careful check on successive model outputs over several days, noting any trends in the way that particular systems are predicted to evolve. Smooth trends will inspire more confidence than drastic changes and in the latter case he will attempt to trace the source of the change by comparing the outputs in great detail. he will also inspect other global model outputs in great detail. He will also inspect other global model outputs e.g. ECMWF, USA-NMC and check for consistency internally as well as between the models. Clearly maximum consistency

inspires greatest confidence. Not unusually, separate models will have large differences beyond day 3 and succeeding forecast runs often indicate a convergence to a common solution; on other occasions both solutions may occur although not simultaneously! The skilled and experienced medium range forecaster uses his knowledge to evaluate the model outputs and provides value adding guidance to the local forecasters.

Summary

Summing up, the CFO carries out a value adding role in support of the local forecasting offices which complements the supply of NWP model products directly to them. The key aspects of this role are:

a) Diagnosis and interpretation of, and influence on the NWP model analysis.

b) Monitoring the accuracy of the NWP model forecast output and advising on deviations to be followed.

c) .Evaluation of confidence in the NWP model output and the interpretation of risk of occurrence of specific weather hazards.

THE LOCAL FORECASTER ROLE

The local forecasting offices represent the interface between the UKMO and most of its customers. Services are provided by a network of regional Weather Centres on the basis of NWP products and advice received from the CFO. The CFO guidance is mandatory for the broad strategy of the forecast but the local forecasters are expected to fine tune the forecasts for local topographical effects. As explained above the broad strategy may be changed following discussion with the CFO Chief forecaster. An important aspect of the local forecaster's role is that of communication with the customer. Face to face briefing or regular telephone consultation is encouraged for all commercial customers, especially when important decisions have to be made on the basis of the forecasts.

The steady expansion of commercial services provided by the Weather Centres means that there is less time available for independent monitoring of the weather except on a really local basis. This implies that increasingly more reliance is placed upon the CFO for accurate guidance. This is a reasonable and acceptable trend but i highlights some problems that are now being addressed by the UKMO.

THE FUTURE

The NWP system is currently being upgraded with global and regional models having increased vertical and horizontal resolution (20 levels, 90 and 45 km respectively) with much improved physical parametrisation. The Mesoscale model is also being upgraded. Given satisfactory analyses therefore we can expect more accurate NWP predictions of significant weather elements as well as the standard pressure, wind and temperature fields. Indeed it will be possible to produce local forecasts directly from the centralised source, adequate for most customer needs.

The communication and display of data by electronic means (VDUs) already established in the CFO and a small number of local offices, will be extended to all local offices within 5 years. This will permit vastly more data, especially NWP products, to be made available to the sharp end of the forecasting organisation. In order to maintain its role under these conditions the CFO will have to produce more comprehensive guidance more quickly. Most of the qualitative text may also become redundant and will need

to be replaced by quantitative guidance e.g. probabilities of occurrence of SIGWX, as the optimum means of communicating guidance to forecasters as a basis of formulating guidance from forecasters to commercial customers.

This evolution in technology will not make the local forecaster redundant; relieved of the task of interpolating centralised guidance to prepare local forecasts, he will have time to evaluate the risk of critical weather events affecting individual customers and he will be better prepared to advise his clients. He will become a consultant, able to provide his customers with the best information that the technology can supply, supported by his own local expertise.

FIG 1. LOCATION AND AREAS OF RESPONSIBILITY OF REGIONAL WEATHER CENTRES THROUGHOUT THE UNITED KINGDOM. THE CFO IS LOCATED IN BRACKNELL WEST OF LONDON.

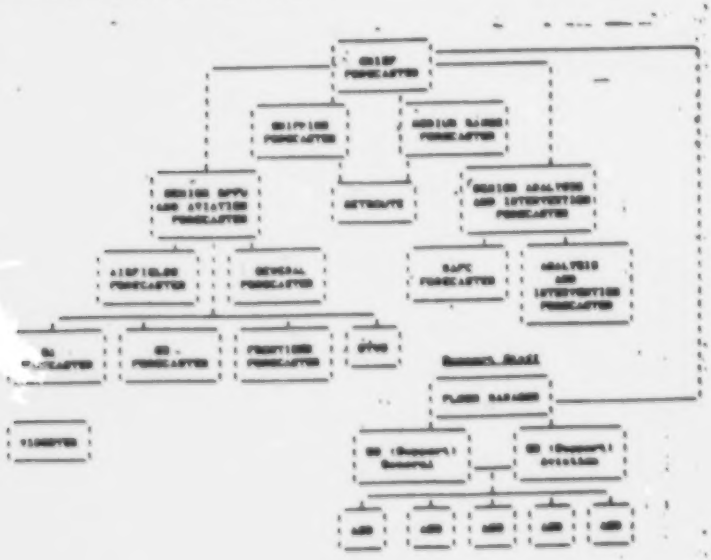


FIG 2. THE STRUCTURE AND HIERARCHY OF STAFF POSITIONS IN THE CENTRAL FORECASTING OFFICE.

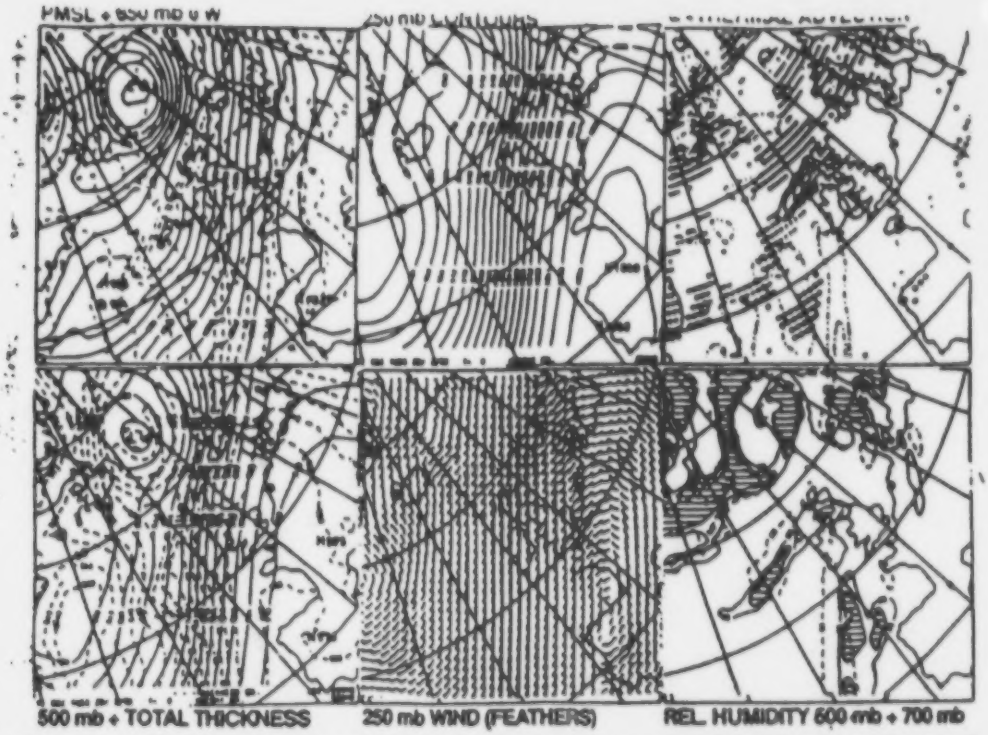
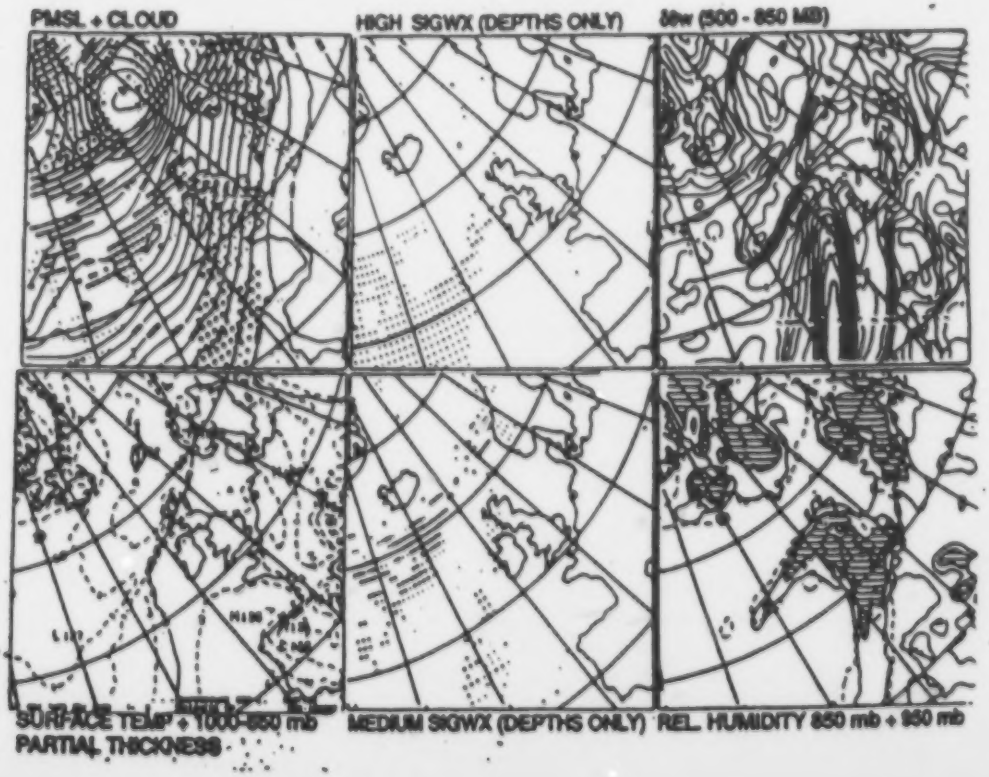


FIG 3. COMBINED FIELDS OF DIAGNOSTIC PARAMETERS DERIVED FROM THE NWP MODEL ANALYSIS. 3(a-f) DISPLAY FIELDS RELATING TO (DYNAMICAL) CAUSE AND EFFECT MECHANISMS. 3c DISPLAYS MEAN 850-500MB LAYER VERTICAL VELOCITY AND THERMAL ADVECTION.

FIG 4. AS FIG 3 BUT CONTAINING PARAMETERS RELATING TO CLOUD AND VERTICAL STABILITY. 4b, 4e DISPLAY MODEL CONVECTIVE CLOUD DEPTHS. BOTH SETS OF COMPOSITE CHARTS ARE COMPARED WITH OBSERVATIONS E.G SATELLITE IMAGERY AND HUMAN CHART ANALYSES .



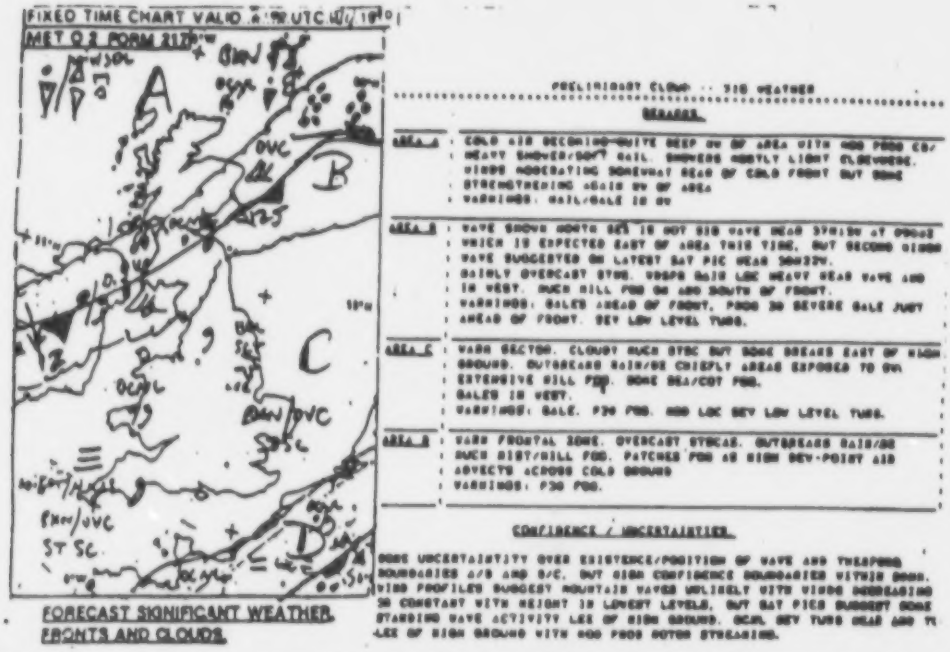


FIG 5. TYPICAL GUIDANCE ISSUED BY CFO TO REGIONAL CENTRES ON A SIX HOUR CYCLE. THIS IS SUPPLEMENTED BY A COMPREHENSIVE TEXT DEALING WITH EVALUATION AND INTERPRETATION OF THE NWP MODEL OUTPUT.

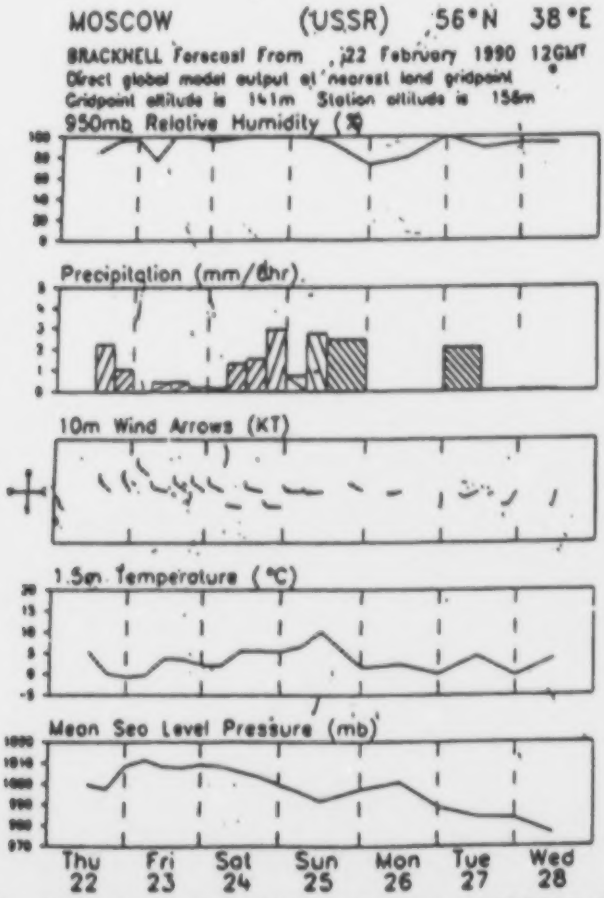


FIG 6. A SITE SPECIFIC FORECAST DERIVED DIRECTLY FROM THE NWP MODEL OUTPUT AND FORMATTED TO MEET THE LOCAL FORECASTER OR CUSTOMERS NEEDS

EFFECTIVE DISSEMINATION OF GOOD SHORT TERM WEATHER FORECASTS

by

Andrew George

Introduction

Current limitations that restrict the effective dissemination of sufficiently accurate short term weather forecasts can be overcome with the birth of Weather Service Offices across the country. If however, the Weather Service Office, is to replace services, in whole or in part, that are currently provided by the numerous Briefing Offices or WO4's within the proposed Weather Service Office's area of forecast responsibility, then more detail must be included in the public forecast in order to accommodate mesoscale differences within it's service area.

Avec l'avènement des Bureaux de Services Météorologiques à travers le pays, les limites actuelles à la dissémination efficace des prévisions météorologiques à court terme pourront être surmontées. Cependant, si le B.S.M. doit remplacer, en partie ou en tout, les services actuels rendus par les BM4 et les bureaux de présentation à l'intérieur de sa région de responsabilité, alors plus de détails devra être inclus dans la prévision publique pour tenir compte des variations à mésoéchelle dans cette région.

Mesoscale Variation

As the Atmospheric Environment Service prepares and plans for new concepts and strategies in providing weather services throughout the nineties, more timely and effective dissemination of accurate weather forecasts and warnings, in particular for day one, is essential in order to improve service to the user and in turn, the credibility of the AES forecaster.

The importance of an accurate short term weather forecast cannot be underemphasized, for the credibility of the forecaster hinges on the accuracy of the forecast for day one.

It is an absolute must that mesoscale differences within a weather office service area or even individual forecast region be considered and incorporated into the forecast. Whether these differences are due to varying local influences or the timing of

approaching or departing weather systems, they must be entailed in the forecast. If not, the forecast to many people listening to it will be incorrect.

For example, let's suppose a cold front in a north - south line, with it's showery weather to the east and clearing to the west, is forecast to move through a certain weather office service area or individual forecast region, from west to east during the day. Because the public forecaster has such a large area of forecast responsibility, and wants to keep the forecast audibly effective, he or she will keep the forecast concise, and is most likely to say something like, "Cloudy with showers today. Clearing tonight."

This forecast of cloud and weather conditions for day one, already susceptible to public criticism, will often find itself grouped with yet other forecast regions. The forecaster is well aware that clearing will begin earlier in western regions or the western part of a region but accepts or is forced to accept this one line forecast for day one. Sure, an explanation of the synoptic situation in the synopsis may be of help for some listeners but does the majority of the general public hear the synopsis? In a recent survey taken in the Yarmouth area, sixty-eight percent of the people claimed that they had never listened to a weather synopsis.

In this example of a passing cold front, would people living in the western portion of the forecast region that did hear the synopsis, understand and retain the information well enough to feel that the forecast of cloud and showers is accurate, if they see sunny skies at ten in the morning? Would they be less critical? Not likely! What the public understands is, "Cloudy with showers. Clearing tonight." To an individual who postpones painting a fence, hanging out a wash, or picnic plans, the forecast was definitely wrong.

As harmless and unavoidable as this forecast seems, it is exactly these oversights or over generalizations that fosters public criticism of weather forecasters, and in turn AES. How can the general public have a high level of confidence in a forecast for day two if these avoidable errors persist in the forecast for day one.

Forecast Regions

It is very true that a forecast for a particular region or regions(weather conditions justifiable)be concise and understandable. A forecast that is unnecessarily wordy will no doubt be ineffective.

Many people, if not most are uncertain about the geographical boundaries of not only the forecast regions in general, but the forecast region in which they live. As indicated in recent survey results from the Yarmouth area, ninety-six percent of the people in that area did not no the boundaries of the weather forecast region in which they lived and eighty-eight

percent could not name the weather forecast region in which they lived. Although this problem is probably not as extensive in other forecast regions, especially metropolitan regions, it makes even an accurate forecast worthless to the listener who is in the dark with respect to weather forecast regions.

A campaign to disseminate information pertaining to forecast regions, whether via the media or distribution of pamphlets would be a seemingly simple solution to this problem, but with the establishment of Weather Service Offices not too far off in the future, a close look at the existing weather forecast regions perhaps should be in order.

With the smaller forecast area of responsibility of the Weather Service Office, forecast regions could be reduced to coincide with each provincial county, and named as such. These areas are not only familiar to the general public living in that area but could be easily familiarized with by tourists or travelers who would only need look at a road map.

With forecast regions of this size, the forecast for each region could be very accurate while maintaining a concise wording format.

Reaching the User

With our present structure, it is very difficult, virtually impossible, for the forecasters at the regional weather centres to provide public forecasts that accommodate with sufficient detail, all the mesoscale influences and/or differences in the timing of weather features throughout their forecast area of responsibility. Thus it is the responsibility of the specialist on duty at the WO4's to tailor the regional forecast while accounting for varying current and forecast meteorological conditions within their service area.

In order for the specialist at the WO4 to expedite an accurate forecast, he or she must not only stay current with the synoptic situation and have a good knowledge of local weather influences throughout the service area but ensure that the forecast is reaching the user. A forecast, no matter how accurate, is useless if it is not being heard. So it is not only important that an accurate forecast is available to the people but it is as well being listened to, listened to with confidence.

Although the day one portion of the regional public forecast is often tailored by the specialist at the WO4, a large percentage of the general public may not hear it. This could be due to a number of reasons.

Even though the tailored forecast is immediately loaded on the ATAD and certainly benefits many, surveys indicate that the majority of people rely on the commercial radio and television stations for acquiring weather information.

Sometimes the tailoring of a forecast may not coincide with a scheduled radio broadcast, so people relying on the radio for

their weather information will not be updated as quickly as should be.

At most radio stations the radio announcer will read the forecast he receives over the wire several times during his or her shift while scheduled broadcasts done from the local weather office will be considerably less. So even if the forecast is tailored by the specialist at the WO4, many people will hear the forecast that is read by the radio announcer.

There are some users that depend on Weather Radio Canada as their source of weather information. Although this is a terrific method of weather dissemination, especially to those for one reason or another, who don't have access to commercial radio or television, or the weather office, a sufficiently detailed forecast, because of the time element, is just not practical. However the accuracy of the forecast suffers.

All of these factors that limit the effectiveness of the Briefing Offices when it comes to informing the general public have the potential of being overcome if sufficiently accurate forecasts are produced by the Weather Service Office.

By having one office that is responsible for forecast production and dissemination, forecasts would be amended when required, not tailored, and simultaneously disseminated via the media, ATAD's, and weather radio.

Conclusion

As Weather Service Offices are born throughout the country over the next twenty years so too should there be an improvement of weather services.

The present factors that hinder the effective dissemination of an accurate forecast, especially for day one, can and should be overcome through efforts to increase media and public awareness and sensitivity about the complexities of meteorological phenomenon and the limitations of providing weather services, and by forecaster consideration of all the local influences and timing differences within the smaller forecast area of responsibility.

Survey results are found on page five

Survey Results

The following are results of a recent survey carried out in the Yarmouth area.

1. People's primary source of weather information:

   Radio.....42%
   T.V.....36%
   Weather Office.....22%
   Weather Radio.....NIL

2. People that have listened to a weather synopsis:

   Yes.....32%
   No.....68%

3. People mainly interested in the weather conditions forecast:

   For first 24 hours...62%
   Beyond.....38%

4. People disappointed in an inaccurate forecast:

   Yes.....54%
   No.....46%

5. Disappointed people that are more disappointed when the forecast is inaccurate for:

   first 24 hours.....82%
   beyond.....18%

6. People that know the boundaries of the weather forecast region in which they live:

   Yes.....4%
   No.....96%

7. People that know the name of the weather forecast region in which they live:

   Yes.....12%
   No.....88%

THE WEATHER SERVICES SPECIALIST

AN OVERVIEW

By

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A.E.S.

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ABSTRACT

This presentation focuses on training within the technical ranks of the A.E.S. More specifically, it will answer the question,"How does one become a Weather Services Specialist?". To fully respond to this question we will explore the:

- entry level knowledge and skills
- training structure and delivery
- job tasks and career progression

for technicians. It is hoped that through this presentation, a clear understanding of the roles and knowledge level of the WSS will be communicated.

RESUME

Cette présentation met l'accent sur la formation dans les rangs techniques du SEA. Plus particulièrement, elle tente de répondre à la question "Comment devient-on Spécialiste de l'information météorologique?". Pour bien répondre à cette question, nous allons explorer :

- les connaissances et capacités requises à l'entrée
- la structure et le mode de formation
- les fonctions et l'avancement professionnel

des techniciens. Cette présentation devrait permettre aux intéressés d'acquérir une bonne compréhension des rôles et du niveau de connaissance des SIM.

INTRODUCTION

Since its inception in the early sixties, the Technical Training and Development Division of Training Branch (AES) has consistently met the challenge of training personnel for several federal departments including Air Traffic Services, Flight Services, Coast Guard, Department of National Defence and Environment Canada. This paper will give an overview of the AES training for its technicians with emphasis on the Weather Services Specialist.

Background

There are many studies * that have been completed in recent years relevant to the changing AES, i.e. what it will look like and what people will be doing in the future. Both studies foresee a system of data acquisition, forecast production and dissemination where:

- Data acquisition will continue to become more automated
- Medium and long range forecasts will be produced at a central location
- Short range forecasts will be produced at "regional" offices
- Dissemination will be enhanced through new technology
- One to one weather consultations will be limited to special cases

Current Trends

The following trends are emerging in the current system of forecast production and dissemination:

- Marketing of services is being done primarily by technicians
- Short range local forecasts are produced at the WO-4 level
- Concentration is on mesoscale phenomena
- Increased specialization in the area of forecast production
- NWP continues to progress and improve in accuracy

With the AES Strategic Plan and its proposed two tier weather services system, new challenges are ahead. The impact of this system is clear:

- Offices will be staffed by a mixture of CS, EG, MT personnel
- A more interdisciplinary approach is required of AES personnel
- Mass dissemination methods will continue to expand
- The observing system will continue its trend towards automation
- Increased pressure from the private sector

It is clear that the AES is changing, and so has the profile of the technician within the ranks. New recruits entering the service must be able to upgrade to higher skill levels than the traditional observing function if we are to maintain an experience base.

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*The Canadian Forecast System Review (Pender Report)
The AES Long Term Plan

Training Response

The challenge posed to training was, "How do we enter the 21st century while still retaining present operations". One of the first steps in any organizational change is to identify the skills and knowledge levels required by personnel to meet the needs. To meet this challenge, Training Branch reviewed its technical training program. This program needed to be responsive to short term regional needs for personnel to maintain existing programs and yet supply recruits who were flexible and able to upgrade their skills to the presentation level. Tesch et al commenced this review in 1985. Five stages of development were defined:

- Survey of regional needs
- Job Analysis from survey results
- Curriculum design
- Delivery of training
- Validation of training

The job analysis defined some 350 tasks performed by the presentation technician in his/her normal course of duties, and a knowledge and skills core list to enable the person to do them competently. This was the basis upon which the Weather Services Specialist Course was built. To date nine (9) courses have been delivered(2 in French and 7 in English) and validation of training through regional surveys of O.I.C.'s and staff has commenced.

Recruitment

It was recognized early that recruitment standards had to change. Our society was becoming more and more capable of offering degree personnel to the system. A look at the statistics for the last three years reveals the academic calibre of personnel entering the system at the ab initio level (see Figure One). In the last year, 94% had post secondary education of which 75 percent had a BSc in faculties ranging from Meteorology and Geography to Chemistry and computer sciences.

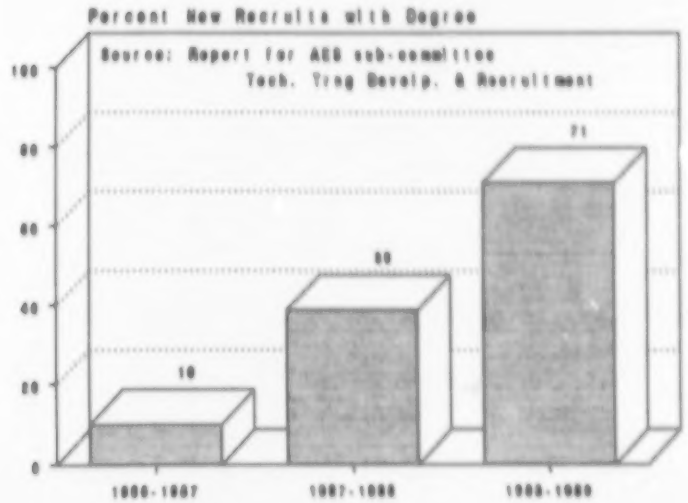


Figure One

COURSES IN TECHNICAL TRAINING

The career progression for technicians varies from region to region. In Central region, there is quite a demand for term positions to accomodate the data acquisition requirements in the High Arctic whereas in Quebec and Ontario, there are more presentation offices (WO-4's) to staff in the longer term.

The following is a summary of the training provided to technicians in AES (see figure two) There are many avenues to pursue, however the normal stream is to progress from MTQC to either the SWOM or AOM or both and then onto the Weather Services Specialist Course.

Meteorological Technician Qualification Course (MTQC)

Module 1 Theoretical and Applied Meteorology (40 Training Days)
The training provided by this module covers:

- The basic meteorological knowledge and skills required by and common to all meteorological technicians employed by AES
- The special knowledge and skills needed by surface and aerological observers to carry out a responsibility for the provision of weather services and weather stations
- Advanced training in preparation for future courses and employment in the AES as a Weather Services Specialist.

Module 2 Safety and Orientation (8 T.D.'s)

The training by this module deals with:

- A general knowledge of the policies, procedures and regulations applicable to all public service employees
- The special knowledge and skills needed to carry out supplementary and other duties in a safe manner.

Following completion of this course (mod 1 & 2) students proceed to courses where they are trained for surface or aerological observing.

Surface Observing and Maintenance Course (SWOM)

Module 3 Surface Weather Observing (32 T.D.'s)

The aim of this module is to provide the special knowledge and skills required by technicians to carry out a full surface observing program.

Module 4 Surface Instrument & Equipment Maintenance (15 T.D.'s)

This module deals with station upkeep of the various instruments and related equipment used in the AES observing program. The aim of the module is to provide all technicians the knowledge and skills necessary to carry out station level maintenance responsibilities.

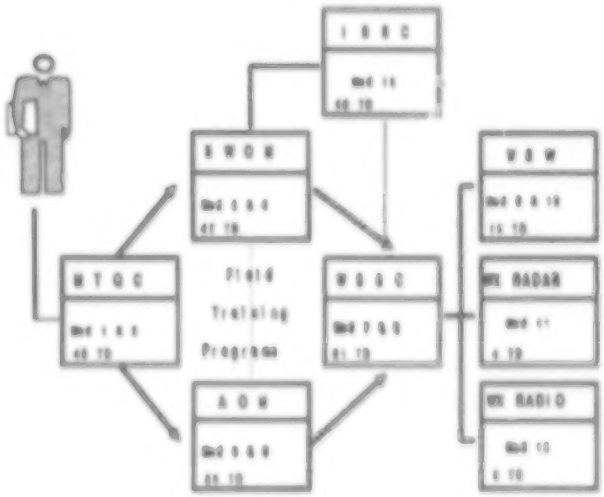
Aerological Observing and Maintenance Course (AOM)

Module 5 Aerological Observing (44 T.D.'s)

The training in this module teaches the students the fundamentals and correct use of equipment and instruments used in the program. It also includes procedures and practices for recording and disseminating data through the communication systems.

Module 6 Aerological Instrument & Equipment Maintenance (41 T.D.'s)

This module forms the second part of the course. The training provided includes basic electrical and electronic theory and operating principles for instruments used in the aerological and solar radiation network.



Technical Training Progression

Figure 2

" The Educational Leave program is offering the Weather Services Specialist the opportunity of becoming tomorrow's Meteorologist or Computer Specialist. These individuals are able to incorporate their experiences in weather services towards those job functions with remarkable results."

Weather Services Specialist Course (WSSC)

Trainees on the WSSC have undergone 5 to 8 months of training within the AES and average 6.7 years of experience [*] as an ice, aerological or surface observer, weather station O.I.C or perhaps in a forecast support role. This gives them a sound background in the business of the AES and a base knowledge of users' needs before commencing the course.

The course is designed to produce a well rounded individual. Scientific integrity is assured through the training in module 7. In addition to the meteorologists on staff, personnel from specific areas are used as guest lecturers on topics such as atmospheric chemistry, numerical modelling,doppler RADAR or perhaps climatic change. Through ongoing development, the course material is assured to be the current thinking.

Source: Met Training Centre WSS Trainee Profile Statistics 1987-1989

With respect to training in weather services, simulations of weather office operations are poised at three strategic locations in the program. The training provided by technical staff is supplemented by the use of experts in the field of media relations to address broadcasting skills.

The following is a breakdown of topics and training times offered on the WSSC.

Module 7 Weather Office Operational Meteorology (27 T.D.'s)

The aim of the module is to provide the specialized skills required to maintain an effective weather watch and produce specialized forecasts.

Subjects covered in module 7 include:

Subject	Hours
- Interpretation and Analysis of Met. Fields	28
- RADAR Meteorology	17
- Satellite Meteorology	10
- Severe Weather Assessment	28
- Short Range Forecasting Techniques	30
- Numerical Weather Prediction	15
- Local Forecasting	32
- Topics of Current Interest and Concern e.g. Acid precipitation, Ozone depletion, Greenhouse Effect etc.	14

Module 8 Advanced Weather Services (34 Training days)

This module provides the training in weather presentation skills. Communication skills are stressed, and media consultants are used to fine tune broadcasting skills and interview techniques used by the media.

Subject matter for the course includes:

Subject	Hours
- Fundamentals of Weather Services	20
- Applied Weather Services	30
- Weather Services for Aviation	26
- Weather Services for the Media	26
- Climatological Services	42
- Simulated Weather Office Operations	79

After completion of the WSSC, personnel must compete for positions in the presentation function. After securing a career as a Weather Services Specialists, field and refresher workshops, described in the following paragraphs, are a part of his/her ongoing training.

Weather Services Workshop

Module 9 Operational Meteorology (11.5 T.D.'s)

Subjects in this module include much of what is covered in Mod 7. It is designed for operational personnel who have been working in the presentation function for some time (average 7 to 10 years). This workshop is used as a refresher, but also to enhance skills in new techniques and technology.

Module 10 Weather Services (3.5 T.D.'s)

This module provides experienced Specialists with additional training in media skills, provided by recognized experts in the field of media relations. Other topics are also included.

Field Training Workshops

Module 11 Weather RADAR (4 Training Days)

This is an on-site workshop concerning RADAR theory, observing and encoding.

Module 12 Weatheradio (2 Training Days)

This is an on-site workshop in voice presentation and the operation of the AES Weatheradio network.

Ice Services Specialist Course

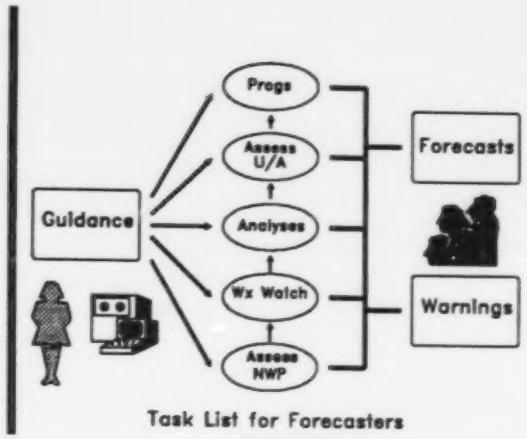
Module 13 Ice Services Specialist Course (40 Training Days)

This course is provided to technicians wishing to pursue a career in Ice Branch. The course includes extensive training in geography, navigation, SLAR interpretation, ice physics and characteristics as well as coding procedures.

WEATHER OFFICE OPERATIONS

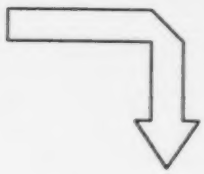
Weather Services Specialist

As stated there are some 350 tasks defined in the job analysis for technicians. With the changing face of the AES, traditional roles of both the MT and EG communities have to be modified to meet consumer demand and a changing work environment. Local forecast are being **produced** at the WO-4 level in every region. These range from marine forecasts for Bras D'Or lake on Cape Breton Island to Avalanche forecasts in the Rockies. Conversely, meteorologists entering the ranks require the communication skills to do traditional presentation functions in Weather Service Offices of the future.

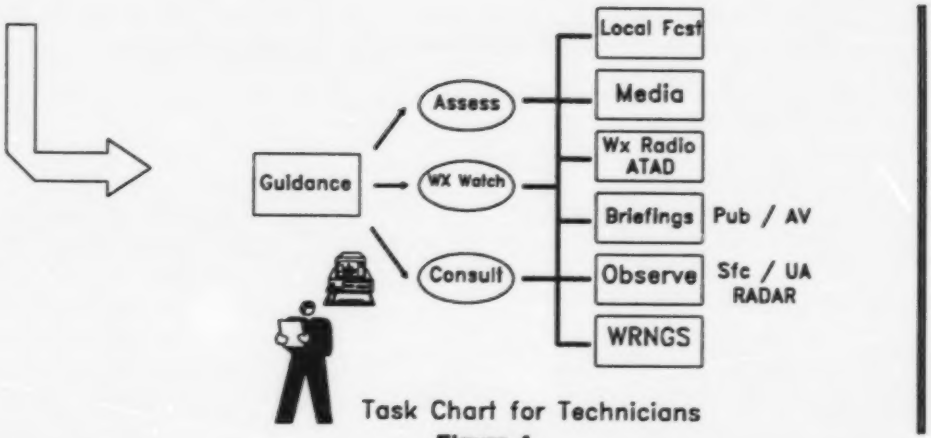


Task List for Forecasters

Figure 3



Guidance from the parent Weather Centre provides extra guidance for the Weather Services Specialist at the WO-4



Task Chart for Technicians

Figure 4

The above flow charts are a simplified comparative view between forecast production and dissemination. Figure three shows a linear progression from initial guidance through diagnosis and analysis to the production of the forecast. Although this task can be exhaustive in scope and complexity, traditionally it has been an uninterrupted flow through stages to the final output. On the other hand, figure four reveals a different experience for the disseminator. Concentration on a task at hand may have to be interrupted at any time to respond to a request for services or to perform a higher priority duty.

Attributes of a Specialist

Although more guidance is provided to the WO-4 from the weather centre, the WSS is often working on his/her own. S/he must all at once be an expert in Meteorology, public relations and broadcasting. Thus, the Specialist develops a talent to make informed decisions quickly in order to manage time effectively. This can be particularly difficult on poor weather days when there are a number of parrallel activities (see figure 4) that must be completed professionally. Warnings, emergency response, observations and weatheradio must take precedent over the person at the counter.The most rewarding aspect of the job is participating in clients' economic decision making. Through the consultation process, or by conducting seminars, you are using your skills to aid members of your community to better use our information and services.

Comparison of Forecast Vs Dissemination Roles

Through my limited exposure on the forecast desk after EG cross training in March 1989, I found the tasks to be much more linear (see Figure 3). All activities on shift are directed at one final product (i.e. the forecast) whereas the technician is producing several "final products" per hour. I found my experiences in weather services granted me the confidence to resolve forecast problems and to put products in the perspective of the user.

There were noted differences in the skills used in each of these two functions. I was used to dealing with the mesoscale, however I usually concerned myself with one particular parameter such as low visibilities hindering an aviator's operations. I now had the time to properly diagnose the situation and perhaps consult with other members of the forecast team. The diagnosis and analysis of fields while working the forecast desk were much more exacting and broader in scope. Two advantages, however, were the lack of distractions from the task at hand and the ability to discuss a forecast problem with the "team".

On the other hand, I sometimes found it stressfull to deal with one task and carry it through in stages from start to finish. My experiences in time management were much different. At the presentation level, you were not always the master of your time, and quick adjustments to your activities were routinely necessary in order to get all tasks done efficiently. This was an exciting part of the presentation function.

Additionally the weather watch function is somewhat different. On the forecast desk, upstream conditions out to 1500 nm and those conditions downstream within the area of responsibility are of importance. For dissemination, downstream weather is as important as upstream due to the requirement for provision of services to users who may be interested in such locations.

Conclusions

The role of the Weather Services Specialist has expanded and continues to expand. New directions forged by Environment Canada in the areas of media relations, atmospheric chemistry, severe weather preparedness, forensic services, environmental emergency response and more have been integrated into the training programs and out to the field. Furthermore, pressure from outside agencies and the private sector have demanded and received expert and professional service from operational staff. The requirement for the Specialist to upgrade his or her knowledge and skill levels is self evident. The WSS's experiences with applied meteorology and their scientific knowledge will continue to provide the AES with an excellent human resource base on which to build its future.

AN EVALUATION OF THE NOVA SCOTIA WEATHER SERVICES OFFICE CROSS-TRAINING PROGRAM

By

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J. Abraham and K. Keddy - Nova Scotia Weather Services Office Test-Bed, Halifax

ABSTRACT

The Nova Scotia Weather Services Office (WSO) Test-Bed was the first to become operational in Canada. In this office meteorological technicians (EG's) have been trained to assume forecasting responsibilities. The EG Cross-Training Program which was developed for this purpose is still in its formative stage, and as such, will continue to benefit from self-appraisal. The now operational EG forecasters are in a position to provide valuable feedback on the training program they received. The evaluation of the EG Cross-Training program by participants in the Nova Scotia WSO will be the focus of this paper. These results will be studied in terms of the application of knowledge and skills learned during the course. As well, the adequacy and relevance of training provided in light of the participants' background knowledge and abilities prior to taking the course will be assessed. As the Strategic Plan of the Atmospheric Environment Service calls for an eventual implementation of Weather Services Offices, results of this evaluation will be essential in forming a basis for refining and improving the training program.

RÉSUMÉ

Le Bureau de services météorologiques (BSM) de la Nouvelle-Écosse a été le premier prototype à devenir opérationnel au Canada. Les techniciens en météorologie (EG) y travaillant ont reçu la formation nécessaire pour assumer certaines responsabilités prévisionnelles. Le Programme de formation mixte pour les EG élaboré en vue de satisfaire ces besoins est toujours en voie de développement et, pour cette raison, il continuera de profiter d'auto-évaluations. Les prévisionnistes EG en poste sont maintenant en position de fournir des informations pertinentes sur le programme de formation reçue. L'évaluation du Programme par les participants du BSM de la Nouvelle-Écosse fait l'objet de cet article. On examine les résultats quant à l'utilisation des connaissances et techniques acquises durant le cours aussi bien que la qualité et la pertinence de la formation donnée en rapport avec le bagage de connaissances et de techniques que possédaient déjà les participants. Le Plan stratégique du Service de l'environnement atmosphérique prévoit la mise en fonction de Bureaux de services météorologiques dans le futur et les résultats de cette évaluation seront essentiels en tant que base pour le perfectionnement et l'amélioration de ce programme de formation.

INTRODUCTION

In the spring of 1989 meteorological technicians from Atlantic region and Technical Training in Cornwall, took part in a training program to prepare them for working in a forecast environment in the Nova Scotia Weather Services Office Test-Bed (Abraham 1990). The course was designed to upgrade technicians from a traditional dissemination role to include forecasting skills which would be used in the WSO environment. The course consisted of four segments: Phase 1 (four weeks in length) which dealt with theoretical aspects of atmospheric structures and processes, satellite imagery, and basic analysis skills. This was followed by a two week remedial segment, where trainees worked on forecast writing self study exercises (to become familiar with the rules and formats of written forecast products) as well as remedial study of Phase 1 material. Phase 2 of the course (nine weeks) dealt with diagnosis and forecasting techniques, and numerical weather prediction. This section of the course was more practical in nature with numerous hands-on and case-study sessions. The final phase of the formal training was composed of a two week simulated forecast environment in which products were prepared in real time. During this simulation, the trainees worked on a shift schedule and performed operational duties modelled after the planned desk schedules in the Nova Scotia WSO.

VALIDATION

The validation phase of a training program is used by the trainers to assure that the abilities learned during formal training are: a) required to perform the tasks on the job, b) are transferred and used on the job, and c) produce an acceptable level of performance. Results from such a study will impact on future programs so that the operational needs are addressed. The participants in this program, being in an ideal position to provide much valuable feedback on the training they received, were surveyed on their opinions for feedback to the formal training program.

Since the training of a forecaster incorporates both a knowledge and skill base, it is necessary to validate these two aspects in the survey. Certain knowledge areas, while not always directly applicable in day-to-day operations, are nonetheless very important to form a scientific foundation for the forecasting process. It is sometimes difficult to determine whether certain knowledge areas are useful to an individual, based on his or her perceptions alone. In this survey, participants were asked whether knowledge learned provided a suitable foundation for formulating conceptual models. In this way, even those knowledge areas that were not directly applicable to operations could be judged on their usefulness in providing a firm scientific base for decision making.

The validation survey comprises three sections: a) A survey of trainee knowledge areas, b) a survey of trainee skill areas, and c) a survey of the supervisors' perceptions of trainees' skill areas.
A brief summary of the responses to the survey follows.

TRAINEE RESPONSES

Trainee Knowledge Prior to the Course

In this section, the trainee indicated the level of knowledge he/she had acquired in various areas prior to coming on course, and thus represents a basic ground level for training.

In terms of atmospheric structure and processes, the participants indicated that they had an adequate prior knowledge in general atmospheric circulation, airmasses and frontal theory, and jet stream structure.

The respondents felt they had virtually no prior knowledge in quasi-geostrophic theory, diagnostic vertical velocity profiles, the energetics approach to synoptic system development, limitations of the idealized frontal model, secondary circulations, basic background of numerical weather prediction (NWP), objective analysis and initialization.

Finally, there were no responses that indicated a fully satisfactory prior knowledge of any of the major modules covered in the course.

Value of Knowledge Gained

The applicability of the knowledge gained during the course was queried in this section. The question asked was whether the knowledge learned in each module was valuable in providing a conceptual model the could be referred to operationally or applied directly. Responses indicated that the knowledge acquired was valuable for the most part with the few exceptions being: construction of vertical velocity profiles, theoretical background in NWP, objective analysis, NWP initialization and forecast cycle, and forecast verification.

Relevancy and Effectiveness of Training Received

Most of the participants felt that the training was effective and the appropriate amount for most of the modules with the following exceptions: NWP model theory and verification - where the training was deemed to be too substantial for what was required operationally; and NWP model output interpretation and reliability - in which the training was regarded as being insufficient and ineffective.

Trainee Skill Level Prior to Course

The perception of the trainee skill area prior to the course had a wider variance than the knowledge areas. The following observations can be made however.

Prior to the course 50 percent or more of the trainees felt their skills were adequate to fully satisfactory in the following areas: basic analysis, tephigram interpretation, radar interpretation, and the diagnosis of fog and restrictions to visibility. While there was some variance, most of the trainees felt that they had limited prior skill in analysis and diagnosis, and all participants had limited or no prior skill at short and medium range forecasting techniques.

Frequency/Relevancy of Skills Learned

The trainees are in a position to evaluate the efficiency of the formal training as determined by the frequency with which they have used these skills since working operationally. Responses generally fell into well defined categories with little variance. Responses indicated that the majority of participants used or applied learned skills frequently. The following exceptions were noted as used seldom, or only a few times: analysis of basic upper air fields, diagnosis of hemispheric scale flow, preparing a formal horizontal weather depiction, jet analysis, construction of formal short and medium range prognoses, and short range forecasting of icing and turbulence.

Relevancy and Effectiveness of Training

The majority of the trainees felt that the training in the skills areas was effective and of the appropriate amount. Training was viewed as being insufficient and ineffective however, in the assessing, inferring and adjusting NWP guidance. Skills training was not regarded as being too substantial in any topic area. In no case did the trainees feel that any of these skills could have been learned through on-the-job training alone.

General Comments

A number of clear messages appear as the result of the trainee survey. From the trainees' perspective, in terms of general course content, indications are that there are no major areas omitted that would be useful to EG forecasters in a WSO. In addition, there seems to be no areas in the course that are extraneous to what is needed on the job. The main issues in training content that did arise were in the areas of application and usage of NWP products, and the diagnosis and forecasting of wind. Other areas, such as satellite imagery, wind and jet analysis, forecast writing, and construction of weather depictions were viewed as needing more extensive treatment and practice. Trainees surveyed indicated that they would have preferred a longer and more extensive simulation period during the course.

SUPERVISOR RESPONSES

In this part of the survey, WSO supervisors were asked to indicate their perceptions of the participants' training based on their experience with the newly trained forecasters. Since skills varied greatly among the participants, supervisors had a difficult time giving responses that applied to all trainees, resulting in some wide variances in the answers.

Frequency of Task Performance

Supervisors were given various task areas for which the participants received instruction and were asked to comment on the frequency with which they are performed operationally. Responses indicated that all task areas trained for were used operationally and only short and medium range prognoses were the direct responsibility of the supervisor.

Relevancy/Effectiveness of Training

In this section the supervisors answered the question "How I feel about the training that the participant received" for various skill areas. This question was designed to probe the expectations of the supervisors regarding the participants' level of performance and whether training coincided with local procedures.

Supervisors indicated significant weaknesses in the trainees' abilities in satellite imagery interpretation, application and usage of NWP output, wind diagnosis and forecasting, analysis over data sparse areas, and medium range forecasting of clouds and weather. Trainees seemed to have trouble interpreting NWP output in terms of conceptual models of the atmosphere, developing a three dimensional picture of various model fields and dealing with inconsistencies that appeared from time to time. For the most part, training followed operational procedures quite closely, with only minor local variations.

General Comments

The supervisors observed a wide variation in skill level among the participants. While in general the cross trained EG's performed well in the operational roles, a number of important observations about the way in which the EG's worked operationally were noted.

Supervisors observed that the discriminating feature among individuals seemed to be determined by how well they diagnosed a particular situation, and how frequent and confident they made their own decisions. In many individuals, there seemed to be a lack of enough critical scientific questioning of data, information, model output, and local guidance. It was observed that in many cases the decision making process was left totally to the supervisor without enough input from the EG forecaster. This may not be solely a reflection of the EG's abilities in these areas. Operational constraints within the WSO often limited the time available for on-the-job development. Furthermore, WSO MT's had the tendency to continue acting as sole guidance producers, traditionally a major part of their role as supervisors in a weather centre.

CONCLUSIONS

1. The EG cross-training program successfully trained experienced presentation technicians to function as operational forecasters.

2. The EG's in general, were satisfied with the course content, but would have liked more time spent on some skill areas (eg. NWP assessment).

3. MT supervisors were also satisfied with the training provided to the EG's. Although the EG's ability to compose forecasts was considered fully satisfactory, their input into the scientific decision making process was less than adequate.

4. The validation survey provided a forum for soliciting important information for the improvement of future cross training programs. Information about amount and depth of training in specific course modules will be used to modify course content and areas of emphasis.

A significant aspect that arose from this survey concerned the way in which an operational forecaster performs his/her duties. While training may be adequate in imparting knowledge and skill areas, a very necessary part of this process is the making of links and developing a "holistic" approach, where the forecaster makes use of all that has been learned. An example of this is in the area of NWP usage in the forecast process. With the recent improvements to the models, forecasting has evolved to the point where proper interpretation and application of conceptual models to NWP output is necessary. Any future Cross-training (or for that matter, any forecaster training) should recognize and deal directly with this issue.

An important issue to be considered in the development of an EG forecaster, is that of critical and independent thinking. With the current course design, this aspect was dealt with in "link" sessions (practice sessions, simulators, etc.); but there is much room for improvement. The WSO experience has shown us that, apart from enhancing these "link" sessions, a well planned and co-ordinated on-the-job training program will be necessary for any future cross-training.

The natural question which follows is "Can the fostering of discriminating scientific reasoning be accomplished during a training program?" Newly trained MT forecasters require a period of career development to attain an appropriate level of reasoning skills. Given an individual with a primarily technical background, the development of a scientifically valid approach to forecasting may be more difficult. The variation in skill levels amongst WSO EG's suggests that while some will develop these skills, others likely will not.

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Operation and Evaluation of the Nova Scotia Weather Services Office Test-Bed (Preliminary Report)

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ABSTRACT

The Canadian Atmospheric Environment Service has as part of its Strategic Plan, the Weather Services Office (WSO) Concept. In order to test some aspects of this approach, a one-year test office has been set up in Bedford, Nova Scotia. Meteorologists and meteorological technicians have been trained to both prepare and disseminate forecast products for the province of Nova Scotia, resulting in a better overall service. However, staffing levels in WSO's must be sufficient to support the necessary and complex communications and computer equipment, as well as a professional development program.

RESUME

Le concept du bureau des services météorologiques (BSM) fait partie du Plan Stratégique du service d'environnement atmosphérique du Canada. Afin d'évaluer ce plan, un "banc d'essai" est établi à Bedford, Nouvelle-Ecosse pour une durée d'un an. Des météorologues et des techniciens météorologiques furent entrainer afin de préparer et disséminer les prévisions pour la Nouvelle-Ecosse. Ceci eut comme résultat un meilleur service pour les clients. Par contre, il doit y avoir un personnel de soutien suffisant pour l'entretien des systèmes complexes d'informatiques et de communications, et pour le programme de développement et de formation professionelle.

INTRODUCTION

The Atmospheric Environment Service (AES) of Environment Canada has embarked on a 20 year Strategic Plan to modernize the Weather Service and make it more efficient. The planned result will be more accurate weather predictions and an improved service to the clients. One aspect of this plan is the Weather Services Office (WSO) Concept. Under this concept, weather service offices (WSO's) would be responsible for both issuance and dissemination of forecast products for smaller areas of responsibility than presently being covered by nine Weather Centres. Concentration would be on the short-range or mesoscale weather, with many of the routine tasks being automated. In addition, the career streams of meteorologists and meteorological presentation technicians would be combined.

In order to test some of the premises of this long term plan, Atlantic Region of AES is currently running an operational test WSO at the Maritimes Weather Centre in Bedford, Nova Scotia. Formal planning for the Test-Bed began in the Spring of 1988 with an invitation for meteorologists (MT's) and meteorological technicians (EG's) to volunteer for participation in the project. Nine Shift Supervising/Senior Meteorologists and nine Operations/Presentation Technicians

were selected for a WSO Cross-Training program. The MT's spent three weeks at the Technical Training Centre in Cornwall, Ontario to review dissemination skills. Subsequently, the EG's were given a rigorous four month course on meteorological theory and forecasting techniques. Details of this course are described in Pearson et al (1990). During the period when the EG's were being trained, the MT's filled behind as operations/presentation technicians at the Maritimes Weather Centre.

The Test-Bed was established in a separate work area adjacent to the Maritimes Weather Centre. Following a two week run-up, the WSO began full operation on August 01, 1989, beginning the one year test period. At that time six cross-trained MT's were assigned to the WSO, with an additional MT acting as WSO Project Manager. Seven cross-trained EG's were placed in the Test-Bed, with the remaining trained staff serving as back-ups.

DESCRIPTION

Office Set-up

In order to help establish potential WSO staff requirements, the Test-Bed was initially set up with two operational forecast positions for each of three eight-hour shifts. The following equipment was placed in the office, with the hope that the two WSO forecasters could run the office with minimal technical support:

- pen plotter to plot charts and tephigrams;
- two Multi-Purpose Display Stations (MPDS) to access digital analyses and prognoses charts and satellite imagery;
- two personal computers at each worksite to be used as terminals on both the regional Hewlett-Packard 1000 and Tandem computer systems for alpha-numeric data display and forecast composition and transmission;
- a sophisticated interactive telephone answering machine. This device is programmed to allow callers to select (through voice or Touch Tone (R) activation) from a number of different weather products, or be transferred to the weather office for consultation;
- a photocopier capable of reproducing and enlarging large charts.

Products and Duties

The WSO Test-Bed is responsible for the public and aviation forecast and warning program for the province of Nova Scotia, the marine forecast for Halifax Harbour, as well as the dissemination normally performed by the Maritimes Weather Centre (MWC). Meanwhile the MWC remains responsible for the public and aviation forecasts for New Brunswick and Prince Edward Island, as well as the regular Maritime marine program.

The two positions in the WSO are each assigned forecast and dissemination tasks, one with public type duties, and the other aviation. Each shift comprises one MT (who is the shift supervisor) and one EG; with both forecasters capable of performing the duties of either position. Table 1 summarizes the products and duties performed by each forecaster.

The WSO initiated a new style of short-term public forecast product for the Halifax metropolitan area for dissemination solely by means of the Automatic Telephone Answering Device (ATAD). By referring to satellite imagery, radar and surface observations, the forecasters add detail to the first several hours of the regular public forecast. This plain language message is produced as frequently as every two hours during rapidly changing weather situations.

Nova Scotia WSO Test-Bed
Products and Duties

Position 1 (Public)	Position 2 (Aviation)
Products	**Products**
- Public Forecast (Nova Scotia)	- Terminal Forecasts (four) (two 24 h and two 12 h)
- Short-term Forecast (Halifax)	- Halifax Harbour Forecast
- Forestry Forecasts	- Halifax Radar Observations
- Climate Bulletins	
Dissemination	**Dissemination**
- Radio Broadcasts (5-10/day)	- Hourly Weather (Weatheradio and ATAD)
- Weatheradio Broadcasts	- Harbour Forecast (Weatheradio ATAD and Cable TV)
- Cable Television text	
- Automatic Telephones (ATADs)	

TABLE 1

EVALUATION and RESULTS

Evaluation Plan

The Test-Bed is being evaluated with regards to various aspects of the WSO Concept. The results from this test will be an important step before final decisions are made regarding implementation of future WSO's in Canada.

Verification of forecast output will be done to attempt to evaluate the accuracy of the products; comparing them with control systems such as climatology, and those produced in previous years by the Maritimes Weather Centre. This may suggest whether forecasts issued for a smaller area of responsibility are better, or whether the combined MT/EG forecast-dissemination was effective.

Surveys of the general public, staff from weather offices within the region, and other users are being conducted to assess whether they perceive any

changes to the service, and if these changes have impacted on forecast quality.

Forecast staff in the WSO are being surveyed to determine their views on the effectiveness of the operation. Problem areas and successes related to such things as office staffing or forecast tools (e.g. techniques and equipment) will be identified.

Finally, the performance of the meteorologists and technicians is being monitored closely by regional managers and supervisors to assess the combining of the forecasting and dissemination functions. The degree to which the EG's are actively participating in the forecast process will be determined, as well as the impact of having forecasters provide direct client consultation.

Preliminary Results

Office Output:
A formal verification of the public and aviation forecasts will not take place until the test is completed in the Summer of 1990. Available verification statistics up to the time of this writing have not suggested any significant changes or trends in forecast accuracy. The first major winter storm of the season was well forecast by the office. Since that time, no significant event was missed, with only one or two false alarm warnings issued.

Aviation forecasts were however amended much more frequently than previously by the Maritimes Weather Centre. The precise reason for this is not clear. EG's do work the aviation desk more often than MT's. Therefore, one suggestion is that the high number of amendments results from a closer weather watch combined with the technicians' better appreciation for operating limits at airports. On the other hand, the increase in revisions may simply result from poorer regular forecasts. However, Ranked Probability Scores for the terminals in question do not yet show any strong evidence in this regard.

Callers to the ATAD were surveyed several times. About 50 percent noticed that the public forecast was updated more frequently; with reference in the forecast now being made to precise times of day, radar and satellite imagery. This in their opinion is making the product much more useful. In fact 70 percent stated that these forecasts were better than those heard through the various media outlets.

One radio station makes it a habit of calling the ATAD frequently to update themselves on the weather situation. They find this product very useful, and refer to the satellite and radar details themselves during broadcasts.

The WSO forecast staff are quite satisfied with the forecast quality. Most feel that the smaller area of responsibility allows for more detail in the forecasts, and ultimately a better product. Furthermore, the forecasters can concentrate on the concerns for one particular area, incorporating local and climatological effects.

Of particular note is the forecasters' support of the local short-term ATAD forecast product. All feel that this product enhances the office credibility. However, the meteorologists feel frustrated by the lack of a good mesoscale observing network, inadequate remote sensing instrumentation and display, and

perhaps even insufficient skill in forecasting mesoscale events. They feel these systems must be in place for proper short-term forecasting.

Operation:
One, if not the major concern with the WSO Concept, is the potential reduction in time available to the professional for study of the atmospheric processes and evaluation of the numerical guidance prior to forecast issue. None of the WSO forecasters are satisfied with the technology available in the office to streamline the operation.

The Multi-Purpose Display System (MPDS) is not yet fully operational, nor was it intended for use as a forecaster workstation. To date it has only been used to access and print analyses and NWP charts for subsequent enlarging and hardcopy use. Satellite imagery has not been available, therefore hardcopy Unifax satellite imagery is being retrieved from the Maritimes Weather Centre for use in the WSO. Access to the office mini-computer has not been available through the MPDS hardware. This has necessitated additional terminals occupying valuable desk space.

The office radar system does not permit animation, nor can it provide Constant Altitude PPI charts. Tops of echoes must be determined by manually raising the antenna until echoes disappear... with each step upwards taking more than two minutes. During days with significant radar echoes present, the forecaster spends as much as fifteen minutes per hour preparing the report (SDCN1) for transmission.

Surface charts are plotted every three hours for analysis. Tephigrams (five to ten) are plotted twice daily. The loading of the charts into the pen-plotter does not always go smoothly. At least once each shift the machine "eats" a chart part way through plotting, resulting in lost time to reload and replot. Up to one hour per day is spent feeding the plotter.

The current weather observations for some 25 stations must be retrieved hourly, formatted to hardcopy, and then read on Weatheradio. This takes about ten minutes of time each hour.

Subsequent to issue, public forecasts are remote loaded to as many as five ATADs (Halifax (English), Halifax (French), Yarmouth, Windsor, and New Glasgow). Forecasts are also typed onto the Cable TV network and read on Weatheradio. This takes in excess of 30 minutes per forecast issue and resulted in an extension of the day shift by fifteen minutes.

The new Interactive ATAD is truly a success story. Prior to its implementation it was not possible for the WSO to handle the 100 or so calls to the office daily. Consequently, it was necessary to have a technician in the Maritimes Weather Centre screen the calls, passing consultation requests to the WSO. Phone logs revealed as many as three-quarters of the calls were for routine weather information.

The new ATAD now allows callers to access most of the forecasts for Nova Scotia, the Halifax Harbour forecast and the latest observations for the metropolitan area. In order to receive personal service, most callers must listen first to the Halifax public forecast. Subsequently, through the interactive feature of the ATAD they may request consultation with either the

WSO, the marine forecaster at MWC, or Regional Climatological Services. To date, this has reduced the number of calls into the WSO to one-quarter of the previous volume. Public surveys reveal that most callers are very pleased with the new service. Regular clients have been given instructions on how to bypass the messages with Touch Tone (R) for rapid access to the office.

Staffing:
ALL the forecasters (MT's and EG's) are enjoying the opportunity to participate in the project. The meteorologists see it as an opportunity to provide feedback to management regarding the WSO Concept. The technicians view it as a chance to use their experience and newly developed skills in a forecast role.

Most of the MT's who volunteered for the project had significant previous dissemination experience. Therefore, it is not a surprise that they all enjoy the consultation role, and are performing well. However, routine dissemination on ATAD's and Weatheradio does not provide the satisfaction of consultative service, and does not require the talents of a forecaster. This may be better suited for clerical positions or automation.

The EG's on the whole are performing very well preparing forecasts. The MT's regard them as an enthusiastic, cooperative and very conscientious group, who are working very hard to develop their forecasting capabilities. However, many of the technicians do not yet have sufficient confidence or ability to properly and fully diagnose the meteorological situation or evaluate the numerical guidance. This results in a reliance on the MT to make most of the decisions regarding the evolution of the weather situation, with the EG subsequently left to compose the forecast.

The technicians are keen to improve their skills as forecasters, frequently asking questions and carefully listening to the MT's explanations. Unfortunately, the number of duties (forecast, dissemination, and "clerical") required on each shift reduces significantly the amount of time the team has to discuss difficult weather situations. This results in slower progress in the EG development.

Shortly after the Test-Bed start-up, the requirement for a third forecaster on day-shift was realized. With the more demanding number of consultation requests during the day, it was virtually impossible for a two-man team to handle any difficult weather situation.

Given that the WSO Test-Bed has only one MT on shift at a time, there is concern amongst the meteorologists regarding the "critical mass" of professionals available for consultation as part of the forecast process, and subsequently for participation in development activities. The Test-Bed does have MT's from the MWC available at all times for consultation. As well, the regular weather centre development infra-structure is in place. But, the question raised is what will happen in a remote WSO?

With only six operational MT's, scheduling is very difficult; especially during periods of professional development and annual leave. Overtime is unavoidable.

The meteorological technicians are in general quite pleased with the staffing levels. Their greatest apprehension is the uncertainty as to the role they will be taking in the forecast process once the one-year test is completed. They do not want to lose the skills they have developed, nor cease performing what they consider to be more challenging, rewarding and enjoyable duties.

Finally, despite the fact that no Computer Systems (CS) staff were specifically assigned to the WSO Test-Bed, much time was spent by this group in getting the office up to an operational state. Day to day operational problems frequently require CS type support. The WSO (or any other forecast office) relies heavily on operational electronic data processing (EDP) and communications hardware, as well as user-friendly and unfriendly software. We have not reached the state where these systems are maintenance-free.

CONCLUSIONS and RECOMMENDATIONS

The Nova Scotia Weather Services Office Test-Bed has successfully completed more than one-half of its one-year trial period. The operation is running smoothly. Indications are that the service to the Nova Scotia public and user community has not deteriorated, and likely has improved significantly; especially in the metropolitan Halifax area. However, before WSO's are implemented in permanent locations, remote from the regional "weather centre", consideration must be given to some of the things learned through operation of the Test-Beds:

- Many experienced Meteorological Presentation/Operation Technicians can be trained to write forecasts, and write them well. The degree that EG's can contribute to the scientific decision-making process likely depends on the individual. Nevertheless, appropriate EG's should be trained and permitted to participate more fully in preparation of forecast products.

- The WSO meteorologists find the combined forecast/consultation role enjoyable and rewarding, with all feeling they are improving significantly the service to the client. However, routine dissemination (Cable TV, Weatheradio, and ATAD loading) is considered "donkey work". These duties should be automated or assigned to clerk-type positions.

- The production and dissemination of short-term forecasts for metropolitan Halifax has been very successful. Nowcasting and short-term extrapolations add precision to the local forecast, not otherwise possible with the regular public format. Reference to observing systems, precise timings and local effects improves significantly the credibility of the product. This style product should be continued and made more widely available.

- The observing systems, meteorologists' workstation or forecast techniques are not presently in place in the WSO to prepare rigorous mesoscale forecasts beyond extrapolation. With the arrival of these systems in the future, a bold effort of operational research and training (e.g. Project STORM in USA) must be undertaken to prepare the forecaster properly, and to ensure effective use of the new tools.

- The Interactive ATAD successfully and significantly reduces the number of routine calls to the WSO. It remains to be seen how a WSO might handle phone consultation for a larger dissemination area. It may be difficult.

- Adequate support staff must be made available to maintain the computer and communications equipment and to handle clerical type duties.

- The smaller forecast office responsible for a reduced area of responsibility has certain advantages:
  Forecast products are more detailed, likely more accurate, with the forecaster appreciating local effects better.
  The forecaster is more aware of weather sensitive user requirements.
  Communication amongst forecast staff is a frequent, open and natural process that ensures consistency within the area of responsibility.

- The smaller office also has several disadvantages:
  Inconsistencies between regions (although seldom evident in the WSO/MWC example) is more likely with additional and remote forecast offices.
  The total number of professionals available for internal forecast consultation and development efforts may be reduced, with staff vacation more difficult to accommodate.
  Overall support staff and back-up systems' requirements (especially computer and communications) likely increase.

- Finally, and perhaps most important, the staff must be willing to accept the changes and be excited about the challenges that face tham. All of the WSO Test-Bed staff volunteered for the project and have been working very hard in their full participation. The conscientiousness and morale of the WSO staff is at a very high level, and is reflected in the quality of the products and services provided.

There is still several months of operation ahead for the WSO before it is dismantled in June 1990. At that time a complete report will be prepared, with more detailed results and firm recommendations.

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TESTING COMPONENTS OF THE WEATHER SERVICES OFFICE CONCEPT IN AES ONTARIO REGION

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ABSTRACT

AES Ontario Region is operating a Weather Services Office (WSO) test-bed at Pearson International Airport to test some aspects of the AES Strategic Plan. The test has two components, an on-line test-bed office to evaluate certain issues related to a combined forecast and dissemination program in a WSO context, and a Techniques Development Unit (TDU) focusing upon the development of meso-scale forecast techniques and procedures. One major aspect of the test is the evaluation of cross-training programs for Meteorologists and Technicians. Problems, issues, successes and strategies associated with the WSO test-bed office will be presented. This will include implementation issues, preliminary evaluation results and human resource issues. A brief report on TDU activities will also be presented.

RESUME

La région de l'Ontario du SEA opère un banc d'essai du bureau de services météorologiques (BSM) à l'aéroport international Pearson pour éprouver certains aspects du plan stratégique du SEA. L'essai porte sur deux composantes; un bureau d'essai en temps réel pour évaluer certains points relié à la préparation et dissémination de prévisions météorologiques dans le contexte du BSM; ainsi qu'une unité de développement de techniques (UDT) visant l'élaboration de procédures pour la production de prévisions à la méso-échelle. Un aspect majeure du banc d'essai est d'évaluer les programmes de formation pour les météorologistes et techniciens. Les problèmes, points controversés, succès et stratègies associés avec le BSM d'essai seront présentés. La question de la mise en marche, les résultats d'une évaluation préliminaire ainsi que le problème des ressources humaines seront aussi présentés. Un résumé des activités de l' UDT sera aussi présenté.

INTRODUCTION

The detailed planning and design of the Weather Services Office (WSO) test-bed in Ontario Region began in late March, 1988. An aggressive and ambitious plan was developed to conduct a one-year on-line test-bed office beginning in April 1989, just one year later. By March 1989 most of the crucial components were in place, or nearly so. This included program design and re-structuring for the test, facility renovations and layout modifications, organizational changes, and the completion of formal cross-training programs for both meteorologists and technicians.

However, a successful appeal regarding the selection process for technician cross-training delayed the implementation of the WSO test-bed office by one full year until April 1990. Following the re-selection of technician participants, the test-bed office was redesigned to accommodate the loss of trained staff over the year. In addition, new training plans were introduced to train new participants and to refresh the skills of the previously trained participants.

A detailed evaluation plan is now in place to evaluate the goals of this particular test-bed office. It is anticipated that the final results from the experiment will be available by next spring. However, much has been learned from the experiences leading up to the implementation of the WSO test-bed office.

PURPOSE OF THE WSO TEST-BED OFFICE

The primary purpose of the WSO test-bed office experiment is to evaluate certain aspects of the WSO concept to assist in the planning and implementation of future weather services offices. Since the test-bed office has common supervision with other operational units, it is not intended to simulate an independently operated weather services office. Only certain issues and aspects associated with the WSO concept can be addressed by this experiment. Although not originally planned this way, the final version of the test-bed office has a larger area of responsibility than anticipated for most future offices. The associated coordination and workload issues will likely prove to be noteworthy.

TEST-BED OFFICE EVALUATION GOALS

Given the context provided above, the evaluation goals of the WSO test-bed office include the following.

* to determine the impact upon the quality of forecast and weather presentation services
* to evaluate the forecasting skills of presentation technicians and the adequacy of the cross-training programs
* to evaluate the weather presentation skills of meteorologists and the adequacy of the cross-training programs
* to evaluate the capability to prepare & issue meso-scale & short range forecast products
* to assess the effectiveness of operations, eg forecast/dissemination modes, best mix of duties, smoothness, workload variability, supervision, etc.
* to determine inter-office and inter-unit coordination & consultation issues
* to assess resource implications and the impact of technological and other support requirements

A variety of methods will be used to evaluate these goals under the guidance and direction of a program evaluator and evaluation coordination committee. Examples include client surveys and feedback, monitoring, analyses, training documentation, supervisor and staff viewpoints, log books, questionnaires, verification results, incident investigation and case studies.

SCOPE OF THE TEST-BED OFFICE

The WSO test-bed office program has two major components, a forecast program, and a dissemination program.

The forecast program includes the public, agriculture and aviation forecasts for Southern Ontario as well as the summer severe weather program when the severe weather specialist (MT5) is on duty. The latter reverts to the Shift Supervisor at other times. The forecast program will also include any meso-scale forecast initiatives which may be developed during the test.

The dissemination program for the test-bed originally included all Toronto Weather Office services except those provided by the weather clerk and the aviation weather services provided through the General Aviation Briefing Office (GABO). In October 1989, the dissemination program was considerably reduced due to the lack of trained WSO test-bed staff following the re-selection of technician participants. The major program components are weatheradio broadcasts, media consultation, and ATAD services including those at three satellite weather offices during the off hours.

WSO TEST-BED OFFICE DESKS

There are four desks within the test-bed office; Aviation South, Public South, Dissemination, and Summer Severe Weather. The latter is a day shift position only and is staffed by MT5 specialists during the summer season, at least. This desk will likely be replaced by a meso-scale forecast desk in winter. Cross trained meteorologists and technicians will work the other three desks on a rotational basis once fully trained. Although each desk has a list of assigned duties and responsibilities, the expectation is that these will be coordinated and shared to find a best fit in the given weather situation.

SUPERVISION AND LEADERSHIP OF WSO TEST-BED OFFICE

The Supervisor of the test-bed office is the Ontario Weather Centre Shift Supervisor who has responsibility for both the Ontario Weather Centre and WSO test-bed Office during the test. In normal circumstances the duty supervisor would be responsible for seven staff on a summer shift. Within the test-bed office the MT5 level meteorologist on duty is designated as team leader, regardless of the particular desk being worked. A similar arrangement exists within the weather centre component. At first, team leader responsibilities were ad hoc in the sense that these were completely at the discretion of the shift supervisor. Recently, as a result of the development of a number of operating problems during the early stages of the test-bed office run-up, a definitive statement of responsibilities for the team leader was instituted to ensure a smoother operation and to provide an easier transition of staff from one team to another.

ACTIVITIES LEADING TO IMPLEMENTATION OF TEST-BED

The crucial events leading up to the full implementation of the test-bed in April 1990 are identified in sequence in Table I. The amount of effort required to fully implement the test-bed program was large, even more than originally anticipated. During the first year of preparations (to March 1989) it is estimated that the equivalent of nine person years of effort were expended by Ontario Region alone in direct support of test-bed activities.

The successful appeal in March 1989 delayed the implementation of the test-bed. This appeal significantly increased the human resources expended. This was partly due to activities related directly to the appeal process and the resulting re-selection of candidates. However, much effort was also expended training and updating the cross-training for the successful candidates in the second selection process, and in changing the design and plans of the test-bed program to accommodate the one-year delay in the test. A significant portion of this effort was spent consulting with and briefing all staff regarding the proposed amendments and new plans.

The appeal had both beneficial and negative impacts during the summer and autumn of 1989. First of all, it slowed the pace of implementation thereby allowing a number of crucial program and support changes to be made well before the test began instead of during the test itself. This in turn ameliorated several staff issues which were becoming quite controversial at the time. The delay also enabled sufficient resources to be placed in the Techniques Development Unit in the autumn to implement some program improvements and to conduct staff development training which had been badly neglected due to test-bed preparations.

On the other hand, the long delay led to a significant lowering of staff morale and increased frustration as time passed. This was mainly caused by the degree of uncertainty which developed since management was not in a position to discuss any future plans or activities which were directly or indirectly related to the re-selection process which, of course, was key to all future plans. This required that the plan be re-activated very quickly once the second appeal was cleared. The new training plan was proposed within two weeks and the test-bed plans were adjusted and updated accordingly. Thorough briefings were given to supervisors and all operational staff at PIA. This was followed promptly with interviews and the completion of questionnaires by fifty-seven operational staff over a six-week period. Significant adjustments were made as a result of this consultation. Staff morale improved rapidly, primarily because the rumours and conjecture which had become prevalent had been replaced by concrete and definitive proposals which were perceived to be realistic and achievable in the timeframes presented.

THE TEST-BED OFFICE RUN-UP

Two week refresher cross-training workshops were presented to refresh the skills of technicians who had completed their formal training nine months earlier. This was followed by on-the-job training (OJT) on the Aviation South desk for the first five technicians, one per forecast team. The second group of technicians took their OJT on the Public South desk once the first group completed their training. This was done partly for logistical reasons and partly to determine whether it was easier for cross-trained technicians to begin on public or aviation desks.

In early January, the organizational structures were changed and the phase-in period for the test-bed office began with two of the four desks included in the test-bed per se, that is, Aviation South and a completely re-configured dissemination desk. The latter desk includes weatheradio services, media consultation and ATAD services as the primary tasks. The public South desk will be included as the OJT for technicians is completed and sufficient trained staff becomes available. The summer severe weather (meso-scale forecast) desk will not become operational until April due to staff shortages.

About one month into the office run-up, consultation meetings were held with supervisors and test-bed participants. Many issues were identified of which several were related to the office run-up and lack of trained test-bed staff on the Public South desk. There were also some procedural changes relating to the fundamental WSO operating principles.

At this point (early March) it is anticipated that the full implementation of the test-bed program will occur in May since the majority of the staff will be fully trained by that time.

OPERATIONAL PHILOSOPHY FOR TEST-BED OFFICE

Wherever feasible and appropriate, only general frameworks and operating guidelines are in place for both the run-up and full test-bed programs to encourage staff to operate in the best possible fashion in a given circumstance and to find new methodologies. The following is the principle provided to test-bed staff.

> "As much as possible each team, under the leadership of the OWC Supervisor and Team Leader (MT5) for the test-bed, will determine exactly how the collective duties and responsibilities associated with the test-bed will be carried out. Although specific duties will be listed for each desk to ensure completeness, the expectation is that the duties and responsibilities will be shared, reassigned, exchanged, adjusted and coordinated by the team to optimize the performance of the team in the given weather situation. The team is encouraged to find new, innovative methods to maximize performance. Only a very general framework is established initially to provide a context within which the test-bed experiment is to be conducted. This framework may be adjusted as the test-bed operation is gradually phased in."

In March, a more definitive statement of responsibilities for the Team Leader was issued to reduce the confusion about roles and to ensure a more uniform approach from one team to another.

TECHNIQUES DEVELOPMENT UNIT

The formation of a techniques development function was from the beginning a basic requirement of the Ontario Region WSO test-bed experiment. This was an explicit recognition of the importance of operational research and development in moving the focus of operational forecasting to smaller scale phenomena in the WSO context. The techniques development unit was to focus upon the development of operational techniques and procedures for short-range and meso-scale forecast and dissemination services, with an emphasis upon the use of Doppler Radar as one of the primary tools. The unit itself is in place for two years from April 1989.

Four main activity areas have been defined for initiatives: Doppler radar applications, workstation development, meso-scale analysis and diagnosis techniques, and satellite applications.

The evaluation of the techniques development unit will focus upon:

* the quality of products developed and the degree of acceptance and utility in operations,
* the resource issues and levels - can such a unit maintain its focus and resources and remain fully responsive to operations, and what benefits can be obtained from such resource increases?
* the organizational aspects, i.e. type of staff, methodologies, reporting relationships, staff capabilities versus work requirements, etc.

Resources for the unit came from existing non-operational staff, operational staff on a part-time basis for specific projects and two term MT-6 meteorologist positions staffed by competition. The unit has benefitted from test-bed delays, which allowed temporarily for higher resourcing, but routine operational staffing problems have had a large impact upon the level of activity. This is especially the case during the summer season when the operational program requirements are high due to the addition of Forestry, Agriculture and Marine programs. This is also the peak season for staff leave requests.

Some interesting observations can already be made. Progress in Doppler radar data studies is dependent upon support from another unit and this, of course, affects progress. At the moment, almost all Doppler developments are done in the Atmospheric Research Directorate, which is short of qualified staff. Two initiatives, a snow squall prediction technique and satellite analysis scheme, have been implemented this past autumn complete with documentation and training courses for all staff. Operational staff has been very impressed with several new support routines implemented by TDU staff. It has been difficult to find individuals for specific projects. Meteorologists with good potential already have preferred areas for development work, and there are many possible areas for development. Also, several of the more qualified meteorologists are reluctant to leave operations on other than a part-time basis. A unit like this TDU may be the best organizational arrangement for best utilizing the skills of operational forecasters.

TEST-BED RESULTS AND CONCLUSIONS

The WSO test-bed office and techniques development unit will operate until March 31, 1991. Final recommendations and conclusions will be published at that time to assist in the planning and implementation of future weather services offices. The issues and preliminary results from WSO test-bed experiment will be summarized and described in the oral presentation of this paper.

TABLE I: CRITICAL EVENTS IN THE IMPLEMENTATION OF THE WSO TEST-BED OFFICE

TIMEFRAME	ACTIVITIES
April-July 1988	Preliminary office design & planning
June-Aug 1988	Design & planning of training programs and selection of staff
Sept 1988	Staff consultation & briefings
Oct 1988	MT Cross-training course presented at TCTI Wall between Ontario Weather Centre and Toronto Weather Office removed
Nov 1988-March 1989	EG Cross-training course (Phase I&II) conducted at Training Branch. MTs performed dissemination duties in Toronto Weather Office to replace EG staff on cross-training. Facility renovations and modifications completed.
March 1989	Appeal re selection of EG participants won by appellants.
	EG cross-training terminated at end of Phase II.
	WSO test-bed office delayed.
April-Sept 1989	WSO test-bed forecast program implemented and operated using OWC MTs
	Re-selection process conducted to select EG participants
	Ensuing appeal lost by appellant
Sept 1989	WSO test-bed program redesigned and training programs adjusted due to changes resulting from selection process.
	Two EG staff begin cross-training in parallel with MOC at Training Branch
Oct 1989	Shift supervisor and staff briefings resulting in further adjustments
Nov-Dec 1989	Staff interviews and questionnaires for all operational staff (57)
	Satellite and meso-scale forecast workshops
	Two week refresher EG cross-training workshop for first group of EGs
Jan. 1990	Re-organization of operational units - OWC, TWO & WSO Test-bed. Phase-in of Test-bed begins with two operational desks and five EG's on OJT. Two week refresher EG cross-training workshop for second group of EGs.
Feb. 1990	Consultation with Shift Supervisors and WSO test-bed staff re operational problems.
	Adjustments made to team leader role
	Four of five EGs complete OJT on aviation desk by end of month.
	Off line training given for three EGs on Public South desk.
	Evaluation plan completed.
March 1990	WSO test-bed MTs and first group of EGs begin rotation through two positions in test-bed
	Three EGs commence OJT on Public South desk

CYCLOGENESIS IN THE WESTERN NORTH PACIFIC OCEAN

By

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Abstract

This study's goal is to quantify the influence of large-scale forcing on surface cyclogenesis. This is accomplished by considering seventy surface cyclones, whose maximum deepening occurs in the western North Pacific Ocean. Cyclone classification is based on this pressure change, ranging from +10 to -40 hPa/24 h. Composite surface, 850 and 500 hPa analyses for each class, constructed from NMC gridded data are used to diagnose quasi-geostrophic omega and frontogenetical forcing and static stability. Explosive cyclones are distinguished by strong downstream 850 and 500 hPa frontogenesis, suggesting deep baroclinicity's importance during the maximum deepening phase.

Résumé

Cette étude a pour but de quantifier l'influence à grande échelle du forçage sur la cyclogénèse en surface. Cette opération peut être faite en observant soixante-dix cyclones de surface, dont le creusement maximum se produit dans la partie ouest du Pacifique Nord. La classification des cyclones repose sur le changement de pression dont l'écart se situe entre +10 et -40 hPa/24 hres. Une grille d'analyse conçue pour la NMC, analysant les surfaces multiples, de 850 et de 500 hPa pour chaque categorie, permet de diagnostiquer à la fois le forçage de la quasi-géostrophique oméga et de la fonction frontogénétique ainsi que la stabilité hydrostatique. Les cyclones explosifs se distinguent par la forte frontogénèse à des niveaux de 850 et 500 hPa, démontrant l'importance de baroclinicité en couche profonde, pendant la phase maximale de creusement.

INTRODUCTION

The western North Pacific Ocean is the location of some of the Northern Hemisphere's most rapidly developing and intense surface cyclones (Sanders and Gyakum, 1980; Roebber, 1984; Gyakum et al, 1989). One area that is especially prone to relatively large numbers of surface cyclones is the western part of the Pacific Ocean over the warm Kuroshio Current.

The research focuses upon the large-scale dynamical characteristics of cyclones whose maximum 24-h intensification ranges from filling values to pressure falls of 40 hPa. Much of the previous research has concentrated upon diagnosis of only explosively-developing systems, whose maximum pressure fall exceeds 24 hPa/24 h.

The data used in this study come from two sources. The first is the cold-season (1 October through 31 March) nine-year compilation (1975 through 1984) of 12-hourly surface cyclones over the region 20-70 degrees N and 120 E eastward to 120 W (Gyakum et al, 1989). The second source is the National Meteorological Center's (NMC's) grid-point analysis for the surface, 850 and 500 hPa during this same time period.

The focus of this research is upon the seventy surface cyclones whose 24-h maximum intensification commenced within the latitude range of 35-40 N, and the longitude range of 140-150 E. As discussed by Gyakum et al (1989), this particular region corresponds to especially high cyclone frequencies. Because of space limitations in this paper, we will show diagnostics from only a subset of cyclones existing in the easternmost five degrees of longitude.

RESULTS

Figure 1 shows composite fields of sea-level pressure for a sample whose subsequent deepening ranged from 11-19 hPa/24 h (SN1) and for another sample whose subsequent deepening ranged from 24-35 hPa/24 h (MB1). Both composite surface cyclones are located downstream of a 500 hPa cyclonic vorticity maximum (not shown), a fact also demonstrated for similar cases in the North Atlantic by Sanders (1986).

The intriguing information from Fig.1 is that the composite surface cyclone in the stronger class of subsequent deepening is considerably more intense than the system found in the weaker class of subsequent deepening. The grid-point geostrophic relative vorticities are, respectively 14 x $10^{-5}s^{-1}$ and 6 x $10^{-5}s^{-1}$.

The dynamical significance of such a relatively strong surface vortex at the onset time of explosive intensification may be appreciated when one examines the vorticity tendency equation,

$$\frac{\partial(\zeta+f)}{\partial t} = -(\zeta+f)\nabla\cdot\underline{v} - \underline{v}\cdot\nabla(\zeta+f) - \underline{k}\cdot\left(\nabla\omega\times\frac{\partial\underline{v}}{\partial p}\right) \qquad (1)$$

Since terms 2 and 3 on the right side of (1) are generally small at the surface cyclone center, the dominant term consists of the product of absolute vorticity and convergence. Thus, the instantaneous surface vorticity tendency will increase, in the presence of a given amount of convergence, as the absolute vorticity increases. Therefore, boundary layer vorticity enhancement *prior* to the onset time of the cyclone's maximum deepening may be an important component in the process of explosive surface cyclone intensification.

As a consequence of the relatively strong circulation at the onset time of the explosive deepening, one might expect to observe particularly strong large-scale patterns of vertical motions and frontogenesis. We have used the 850 hPa fields of geopotential height and temperature to compute the Q-vectors, their horizontal divergence and the frontogenetic forcing at this level. Hoskins et al (1978) introduced these vectors to diagnose the adiabatic, inviscid forcing for the quasi-geostrophic omega equation. Hoskins and Pedder (1980) have discussed the relationship of Q vectors to synoptic-scale vertical circulations.

Figure 2 shows that the MB1 cyclone has a markedly stronger couplet of Q-vector convergence (ascent) and divergence (descent), respectively ahead of and behind the system than is found for the SN1 composite. The subsequent 12-h tracks show the MB1 composite to be propagating into a region of warm frontogenesis that is substantially stronger than that found for SN1. Such environmental conditioning may also be unique to explosive cyclogenesis.

Acknowledgments

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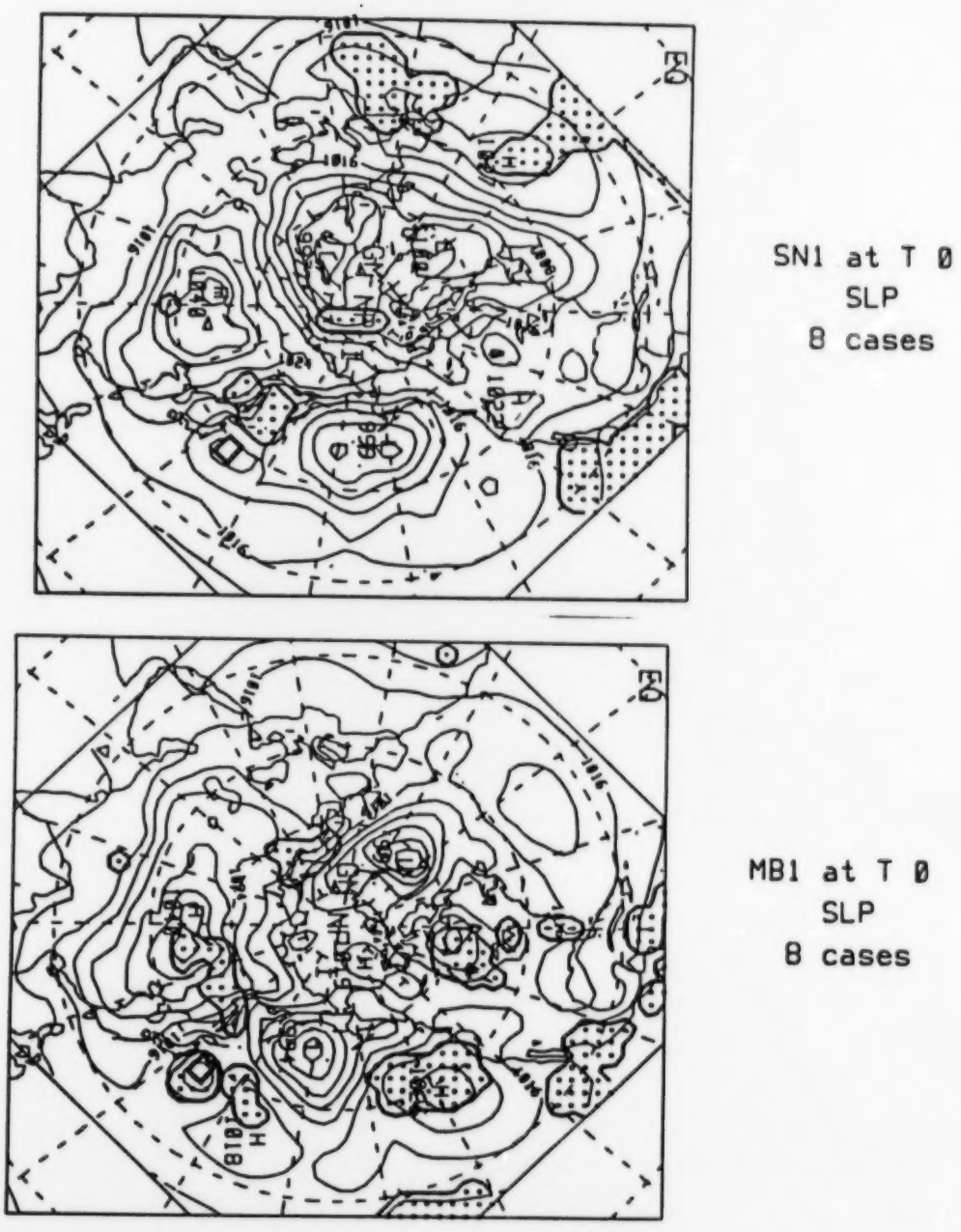

Figure 1. Composite sea-level pressure (hPa, contour interval of 4 hPa) analyses for both the SN1 and MB1 samples. The box in each chart indicates the region in which the sample cyclones are located. Areas where climatological pressures differ from composite values at the 95% confidence level are stippled.

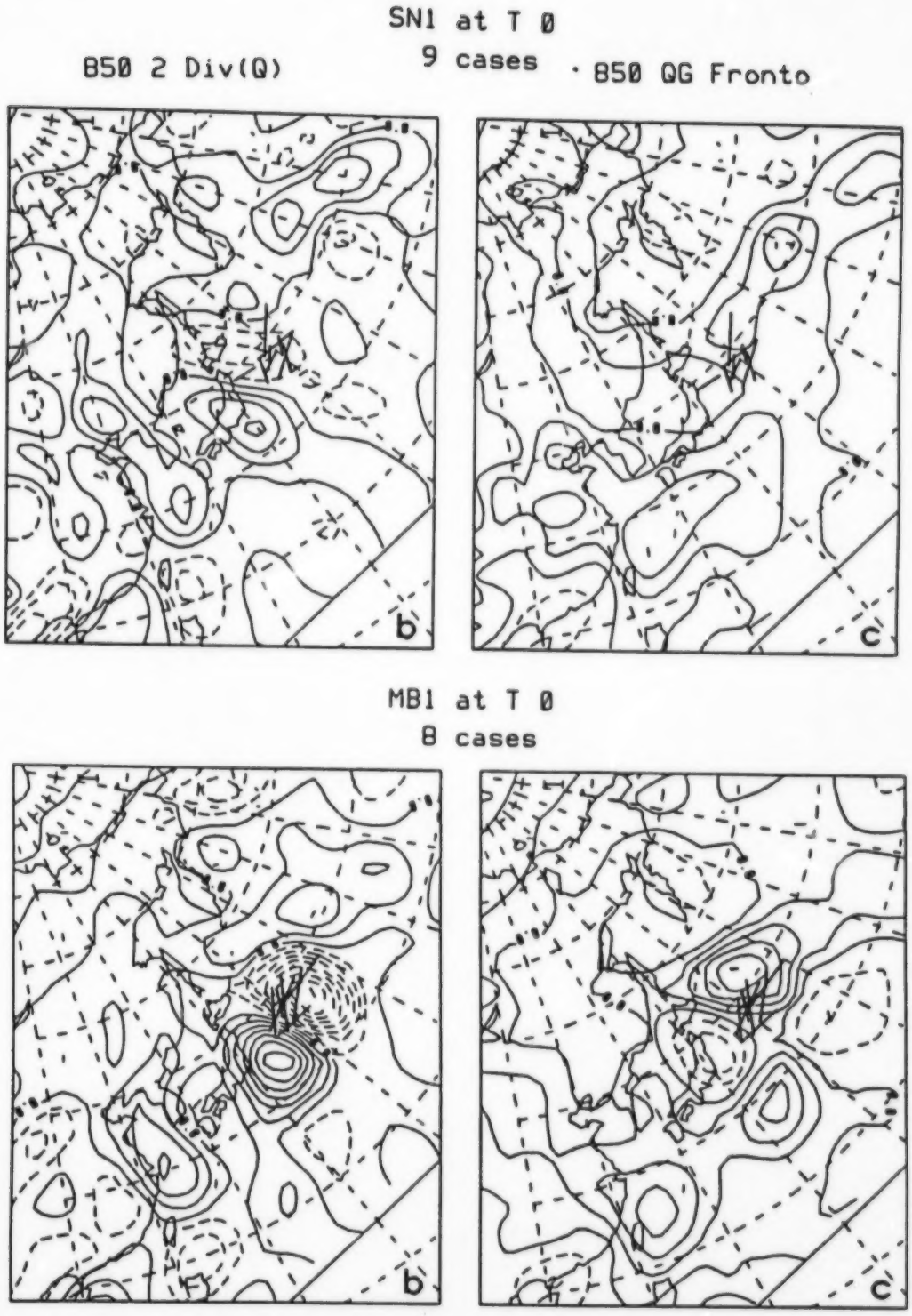

Figure 2. Composite Q vector diagnostics for 850 hPa for each of the samples SN1 and MB1. The left column shows $2\ (\nabla \cdot \vec{Q})$ with a contour interval of 2.0×10^{-16} K m^{-2} s^{-1}; dashed contours indicate convergence of the Q vector. The right column shows $\vec{Q} \cdot \nabla \theta\ /|\nabla \theta|$ with a contour interval of 30×10^{-12} K m^{-1} s^{-1}; dashed contours indicate frontolysis. The cyclone tracks for the subsequent 12 hours are also shown.

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